ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

HMAP | CENSUS OF MARINE LIFE | OGS | Oceans EUR-OCEANS CONSORTIUM | ICTP

WHEN HUMANITIES MEET ECOLOGY

Proceedings of the HMAP International Summer School

HMAP (History of Marine Animal Populations)
Mediterranean and Black Sea - International Summer School 2009

When humanities meet ecology

Historic changes in Mediterranean and Black Sea marine biodiversity
and ecosystems since the Roman period until nowadays

Languages, methodologies and perspectives

***

Abdus Salam International Centre for
Theoretical Physics (ITCP) - Trieste (Italy)

31.08.2009 – 04.09.2009

31st August - 4th September 2009
Trieste (Italy)

Proceedings

ISPRA
Istituto Superiore per la Protezione
e la Ricerca Ambientale

HMAP International Summer School:
When Humanities Meet Ecology

Historic changes in Mediterranean and Black Sea marine biodiversity and ecosystems since the Roman period until nowadays. Languages, methodologies and perspectives

31st August – 4th September 2009, the *Abdus Salam* International Centre for Theoretical Physics, Trieste (Italy)

Edited by
Gertwagen R., Fortibuoni T., Giovanardi O., Libralato S., Solidoro C. & Raicevich S.

Legal Disclaimer

ISPRA is the Italian National Institute for Environmental Protection and Research established by the Italian Law 133/2008, as published in the "Gazzetta Ufficiale" n. 195, August 21st 2008. The Institute performs the functions of three former institutions: APAT (Agency for Environmental Protection and Technical Services), ICRAM (Central Institute for Applied Marine Research), INFS (National Institute for Wildlife).

ISPRA – Istituto Superiore per la Protezione e la Ricerca Ambientale
Via Vitaliano Brancati, 48 – 00144 Roma
www.isprambiente.it

ISPRA, Serie Atti 2010

ISBN 978-88-448-0470-1

Technical-Scientific Coordination on the behalf of ISPRA: Saša Raicevich
ISPRA - STS Chioggia, Loc. Brondolo, 30015 Chioggia
Tel: (+39) 0415543933
sasa.raicevich@isprambiente.it
http:// www.hmap-medbs-summerschool2009.org

Editing: Gertwagen R., Fortibuoni T., Giovanardi O., Libralato S., Solidoro C. & Raicevich S.

Graphic elaboration: ISPRA

Cover design: Franco Iozzoli

Typographic coordination
Daria Mazzella
ISPRA – Settore Editoria

Administration
Olimpia Girolamo
ISPRA – Settore Editoria

Distribution
Michelina Porcarelli
ISPRA – Settore Editoria

Layout and Print
Tipolitografia CSR - Via di Pietralata, 157 - 00158 Roma
Tel. 064182113 (r.a.) - Fax 064506671

Printed in January 2011

To be cited as:
Gertwagen R., Fortibuoni T., Giovanardi O., Libralato S., Solidoro C. & Raicevich S. (Eds.), 2010. When Humanities Meet Ecology: Historic changes in Mediterranean and Black Sea marine biodiversity and ecosystems since the Roman period until nowadays. Languages, methodologies and perspectives. Proceedings of the HMAP International Summer School. 31st August – 4th September 2009, Trieste (Italy). ISPRA Serie Atti 2010, Rome, pp. 360.

Authors of the Proceedings contributions

Constantin ARDELEANU[1], Laura AIROLDI[2], Carmen ALFARO GINER[3], Vincenzo ARTALE[4], Michael W. BECK[5], Tønnes BEKKER-NIELSEN[6], Chiara BERTOLIN[7], Ferdinando BOERO[8], Fulvia BRADASSI[9], Guido BRESSAN[9], Dario CAMUFFO[7], Igor CELIĆ[10], Matthew J. COLLINS[11], Oliver CRAIG[11], Francesco CUMANI[9], Tomaso FORTIBUONI[10, 16], Gianluca FRANCESCHINI[10], Ruthy GERTWAGEN[12], Otello GIOVANARDI[10], Jennifer HARLAND[11], Tsegay Fessehaye KASSA[13], Kristine KORZOW RICHTER[14], Maja KRŽELJ[15], Paolo LAZZARI[16], Simone LIBRALATO[16], Salvatore MARULLO[4], Anna RABITTI[17], Saša RAICEVICH[10], Rosalia SANTOLERI[18], Cosimo SOLIDORO[16], Konstantinos I. STERGIOU[19], Francesco TIBONI[20], Clive TRUEMAN[21], Nienke VAN DOORN[14]

1 "Dunărea de Jos" University of Galaţi (Romania)

2 Dipartimento di Biologia Evoluzionistica Sperimentale and Centro Interdipartimentale di Ricerca per le Scienze Ambientali in Ravenna, University of Bologna, Ravenna (Italy)

3 University of Valencia - Department of Ancient History, Valencia (Spain)

4 Italian National agency for new technologies, Energy and sustainable economic development (Enea), Casaccia, Roma (Italy)

5 The Nature Conservancy and Institute of Marine Sciences, University of California, Santa Cruz (United States of America)

6 University of Southern Denmark, Kolding (Denmark)

7 Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR), Padova (Italy)

8 DiSTeBA - University of Salento, Lecce (Italy)

9 University of Trieste - Life Sciences Dept., Trieste (Italy)

10 ISPRA - Italian National Institute for Environmental Protection and Research, Chioggia (Italy)

11 BioArCh, Department of Archaeology, Biology and Chemistry, York (United Kingdom)

12 Coordinator and teams leader of the HMAP Mediterranean and the Black Sea project, University of Haifa and Oranim Academic College, Haifa (Israel)

13 National Fisheries Corporation, Fishing Enterprise, Massawa (Eritrea)

14 Department of Biology, The Pennsylvania State University, University Park, Pennsylvania (United States of America)

15 Department of Marine Sciences - Polytechnic University of Marche (Italy) and Centre for Marine Studies - University of Split (Croatia)

16 National Institute of Oceanography and Experimental Geophysics (OGS), Trieste (Italy)

17 Department of Physics, University of Trieste, Trieste (Italy)

18 Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR), Rome (Italy)

19 Aristotle University of Thessaloniki, School of Biology - Department of Zoology, Thessaloniki (Greece)

20 AIASub – Italian Society of Underwater Archaeologists (Italy)

21 University of Southampton Waterfront Campus, European Way, Southampton (United Kingdom)

INDEX

SECTION 1 – *WHEN HUMANITIES MEET ECOLOGY: THE PAPERS*

SECTION 2 - *STUDENTS' FIELDS OF RESEARCH*

INTRODUCTION

Ruthy Gertwagen[1]
ruthygert@gmail.com

Saša Raicevich[2]
sasa.raicevich@isprambiente.it

Cosimo Solidoro[3]
csolidoro@ogs.trieste.it

This volume is the product of the five days Summer School (31st August -4th September 2009) entitled "When Humanities meet Ecology. Historic changes in Mediterranean and Black Sea marine biodiversity and ecosystems since Roman period until nowadays. Languages, methodologies and perspectives". The Summer School, initiated and organized by Prof. Ruthy Gertwagen, the co-ordinator and teams leader of the History of Marine Animal Populations (HMAP) of Mediterranean and Black Sea programme, was held as "hosted activity" at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste (Italy); it was co-organised by Dr. Saša Raicevich, Dr. Otello Giovanardi and Dr. Tomaso Fortibuoni (ISPRA – *Italian National Institute for Environmental Protection and Research*; Chioggia, Italy), and by Dr. Simone Libralato and Dr. Cosimo Solidoro (OGS - *National Institute of Oceanography and Experimental Geophysics*; Trieste, Italy). The Summer School was funded by Sloan Foundation through HMAP, ISPRA, and the EU Network of Excellence EUR-OCEANS through OGS.

Twenty-six students from a vast global spectrum of countries, including Europe (Italy, Greece, Poland, Romania, Austria, Croatia and Denmark), the Middle East (Israel), Northern Africa (Tunisia), South-Eastern Africa/The Horn of Africa (Eritrea), and the United States (Maine/Hampshire and Maryland/Washington) attended the Summer School. Among the students, that ranged from MA up to Ph.D. holding various academic positions, only two came from the Humanities. The team of speakers was international as well (UK, Italy, Spain, Denmark, Malta, Greece and Israel) and came from a wide spectrum of disciplines, including: history, marine environmental history, marine ecological history, archaeology, underwater archaeology, marine zoo-archaeology, ecology, oceanography and climate science.

1 Co-ordinator and teams leader of the History of Marine Animal Populations (HMAP) of Mediterranean and Black Sea programme – University of Haifa and Oranim Academic College, Haifa (Israel).
2 ISPRA - Italian National Institute for Environmental Protection and Research.
3 OGS - National Institute of Oceanography and Experimental Geophysics.

What is the HMAP Mediterranean and Black Sea project?

The HMAP global initiative (History of Marine Animal Populations; http://www.hmapcoml.org) represents the historic arm of the Census of Marine Life (CoML), which is a global network of researchers engaged in a ten-year scientific initiative to asses and explain the diversity, distribution and abundance of life in the oceans (http://www.coml.org). CoML was conceived in 1999 due to the awareness to and concern with the global decline of marine biodiversity, because of the negative and tragic impact of human interaction with the oceans in terms of overfishing, habitat destruction, pollution, biological invasions and climate change. The final goal of this project was "to forecast, measure, and understand changes in the global marine environment, as well as to inform the management and conservation of marine resources". In fact, "understanding historical patterns of resource exploitation and identifying what has actually been lost in the habitat is essential to develop and implement recovery plans for depleted marine ecosystems".[4]
When scientists realized the importance of the humanistic disciplines for reconstructing the history of the marine environment, the marine environmental field that had been until the last decade the realm of only marine ecologists and oceanographers, was expanded to include Humanities. The collaboration between ecologists and historians initiated in 1999 under the umbrella of the HMAP programme that billed accordingly its research approach as multidisciplinary unique in drawing Humanities (marine history, archaeology) and Science (ecology, oceanography, etc.) into collaborative study, while aiming to keep the balance between historical and ecological studies. This collaboration has led to the emergence of a new scientific community of marine environmental historians and historical ecologists.[5] After ten years of research, this global project claims to have succeeded to enhance the knowledge and understanding of how the diversity, distribution and abundance of marine life in the world oceans has changed over the long-term, by analyzing data that date back to periods before and after human impacts on oceans. In particular, it became relevant to focus on the dynamic interplay between anthropogenic and natural factors in the evolution of marine ecosystems. This knowledge is exhibited on the HMAP Dataset, with open access facilities that are disseminated through the Ocean Biodiversity Information System (OBIS: http://www.iobis.org). At the same time, HMAP sets the targets for future

4 A citation from Poul Holm's, chair of the HMAP project, concluding remarks of the second HMAP International Conference Oceans Past II that was held in Vancouver, Canada on May 2009: http://hmapcoml.org/news/documents/CoML_Oceans_Past_Public_Release_05.23.pdf.
5 HMAP has paved the way for the establishment of a number of new academic posts and has enabled scholars belonging to many participating universities to start new environmental and maritime history courses at undergraduate and doctoral level at the Old Dominion University (Virginia, US), Dalhousie University (Halifax, Canada), Simon Fraser University (Vancouver, Canada), Roskilde University (Roskilde, Denmark), University of Hull (Hull, UK), Greenwich, and Exeter in England, Trinity College Dublin (Ireland), Södertörn, Bergen, Tromsø, Stavanger, Bremen, St Petersburg Russia, Perth and Murdoch, Australia.
6 On HMAP's initiation, goals and methodology, see: Poul Holm, Tim D. Smith and David J. Starkey (eds.), *The Exploited Seas: New Directions for Marine Environmental History*, in *International Maritime Economic History Association, Maritime Studies, Research Unit*, 2001; For a detailed phrasing of goals, methodology and collected data see the above-cited net-site: http://www.hull.ac.uk/hmap/AboutHMAP/AboutHMAP.htm.

environmental management policies to prevent, among others, proceeding in depleting oceans' resources and to rebuild and reconstruct dying and vanished marine ecosystems.[6]
HMAP Mediterranean and Black Sea project was born by and inserted into HMAP global research programme in late Fall 2004, when a workshop was organized in Barcelona to foster collaboration between scientists and historians dealing with fisheries in the Mediterranean and Black Sea. This initiative was followed by a workshop, held for three days in September 2006 in Chioggia (Venice, Italy), that dealt with "Human-environment interactions in the Mediterranean Sea since the Roman period until the 19th century: an historical and ecological perspective on fishing activities". The workshop focused on the state of the art of the knowledge dealt with by experts of diversified fields: historians, archaeologists, oceanographers, marine biologists and ecologists. That was the character of the proceedings volume produced as a result of the workshop, which was published in Italian, with the introduction and the proceedings' short abstracts in English.[7] This Summer School is therefore the third initiative organized in the framework of the HMAP Mediterranean and the Black Sea project.

Why a Summer School?

Having been initiated in late Fall 2004, the HMAP Mediterranean and Black Sea programme is only at its infancy. Marine environmental history and marine historical ecology, dealing with periods that date back well before the birth of "modern science", are not studied as formal disciplines by their own merits or at all in the various schools and universities in the countries that encircle the Mediterranean, not even in those academic institutions that contain diversified maritime studies, such as: oceanography, ecology, biology, history and underwater archaeology.
However, this figure is changing and multidisciplinary studies on historical ecology are now receiving more attention than in the past. For instance, the University of Trieste (Italy) had a Ph.D. thesis on the reconstruction of the history of fishing exploitation over the last two centuries and the evaluation of its ecological consequences on marine animal populations

---

7 The workshop was funded by the European Census of Marine Life (EuroCoML), matched by local organizations: *Associazione "Tegnùe di Chioggia"*, *Regione Veneto*, *Fondazione della Pesca di Chioggia*, ICRAM (*Istituto Centrale per la Ricerca Scientifica e Tecnologica Applicata al Mare*, STS Chioggia) (now ISPRA). The proceedings volume, entitled *Il Mare. Come'era. Le interazioni tra uomo ed ambiente nel Mediterraneo dall'Epoca Romana al XIX secolo: una visione storica ed ecologica delle attività di pesca, was edited by the organizers in chief of the w-p: R. Gertwagen, S. Raicevich, T. Fortibuoni, O. Giovanardi, and it was published in Italian in 2008 by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale*) as *Supplementi ai Quaderni dell'ex ICRAM*, and was funded by the *Associazione "Tegnùe di Chioggia"* and the *Regione Veneto*. For a rationale explaining the full inclusion of the Black Sea in the HMAP Mediterranean project, see in the same volume the *Introduction*, by R. Gertwagen (pp. 15-24).

8 The Ph.D., carried out by Tomaso Fortibuoni, was supervised by Dr. C. Solidoro (OGS, Trieste), with Dr. S. Raicevich (ISPRA, Chioggia) as a co-supervisor (both coordinating the scientific approach), and with Prof. R. Gertwagen of the University of Haifa and Oranim Academic College who, as a co-supervisor, coordinated the historic approach. The Ph.D. project was part of the "Biomonitoring methodologies of environmental disturbance" Ph.D. programme and was supported by the *Regione Veneto* through the *Associazione "Tegnùe di Chioggia"* in collaboration with ISPRA (Chioggia), and was co-funded by the Sloan Foundation through HMAP global program. The VeLNA project is coordinated by Prof. Ruthy Gertwagen.

and communities in the Northern Adriatic Sea[8]. As a whole, the research makes part of the HMAP Mediterranean and the Black Sea project, entitled: "Human-environment interactions and marine animal population dynamics in Venice's Lagoon and the Northern Adriatic Sea (VeLNA), from the 12th century to the modern period".
The participation of only two students of the Humanistic field, albeit the Summer School's advertisement in various Humanities faculties or through web-nets related to historic and archaeological fields, pinpoints to the alienation of the historic discipline to whatever concerns science, even if it involves historic aspects. The 2006 workshop highlighted, among others, the gaps between scientific and humanistic approaches, and eventually problems in methodology of research, thus suggesting the need to organize this Summer School. Because of the above-mentioned disciplinary differences among the students and the speakers that attended the school, one of its major goals was to consolidate the new fields of marine environmental history and marine ecological history to both senior and young researchers, and to enhance their application to detect and reconstruct long-term changes in marine biodiversity and ecosystems since remote historic periods (in this case since the Roman period) until nowadays. These disciplines in combination are essential to implement healing measures and recovery plans for depleted marine ecosystems and species in the Mediterranean and Black Sea, two marine areas that are known to be among the earliest heavily fished marine ecosystems in the world. The importance of the historic dimension for these purposes was explicitly expressed by the first speaker in the Summer School, Matthew Camilleri of the General Fisheries Commission for the Mediterranean (FAO).
By introducing marine ecological history and marine environmental history, the Summer School focused on the methodological approaches involved: the multidisciplinary and the interdisciplinary, and the difference between the two. Multi- and interdisciplinary approaches bridging over Humanities and Scientific disciplines were, by their own right, alien to the attendants, since it is very rare, if at any at all, to find them taught in high-level academic schools. Quite often than not, each scholar is focused on his/her own intra-field of their main disciplines.
The Summer School therefore introduced the various fields of Humanities and Science that concern our subject matter: history, archaeology, zoo-archaeology, anthropology, oceanography, ecology, climatology and modeling, while aiming at providing - as much as possible - a better understanding of each discipline's language, needs and potentials, to bridge over the gaps between Humanities and Science. Bridging over the gaps will promote a multi and interdisciplinary study of marine environmental history and marine ecological history in the framework of the HMAP programme, with special emphasis to the Mediterranean and the Black Sea.
Methodology characterizes, accordingly, this volume. Due, however, to the diversified academic and research background of the students attending the Summer School, each lecturer was required to present the basics of his field of study relevant to potential bridging between disciplines, to introduce the methodology employed and finally, to end by implementing it to historic periods.
Although focusing on the Mediterranean and Black Sea the volume, due to its unique character, can be applied to other systems worldwide. We, therefore, have decided to publish it in English as well as in Italian. Furthermore, the volume also includes short papers introduced by the attendants/students on their current research. Indeed, the organizers

thought the Summer School to be a good opportunity for the students attending it to introduce their field of study, to profit from an experience of talking in front of an academic audience, to have a constructive feedback and to publish their communications as a practical experience for their future academic life.
Originally written in English, all papers were translated into Italian by T. Fortibuoni, O. Giovanardi, M. Romanelli and S. Raicevich with the aim of respecting, as much as possible, the meaning and style of the original manuscripts.

BRIDGING OVER "STORMY GAPS" BETWEEN HUMANITIES AND SCIENCE IN MARINE ENVIRONMENTAL HISTORY'S AND MARINE ECOLOGICAL HISTORY'S METHODOLOGY

Ruthy Gertwagen
University of Haifa and Oranim academic College, Haifa (Israel)
e-mail: ruthygert@gmail.com

Key-words: *humanities, science, marine environmental history, marine historical ecology, multidisciplinary, interdisciplinary, methodology*

The paper aims to introduce the disciplines of marine environmental history and marine historical ecology and the problems of methodology they have to do with, especially as two detached fields of study are involved: Science and Humanities. Regarding, however, our subject matter, history is the common denominator. Highlighting and define the problems, I believe, would with benevolence facilitate finding ways, to overcome them. I find it a rare chance, since we deal with young and new disciplines. Since, however, these new fields are involved, as we shall see below, with wide spectrum of sub disciplines, the subject matters discussed and the approach suggested by the present paper can easily be applied to other fields of study beyond marine environmental history and marine ecologic history.

As a matter of fact, one should emphasize that the emergence of environmental history as a discipline is new, since only the last two decades at the most. The various scholarly journals, occupied with this subject matter and only initiated in the early 1990s, attest to this fact.[1] Furthermore, only few academic institutions have adapted this new discipline. In some of these, the historians had to change departments to new ones, due to the conservative and common stream of historians' lack of understanding of the close relation between environment, ecology and history.[2]

On the other hand, it should be stressed that environmental history of the Mediterranean and Black Sea has already been dealt with in the 1960s by Fernand Braudel's monumental opera, *The Mediterranean and the Mediterranean Word in the Age of Philip II*, by which he mainly discussed the role of the Mediterranean and Black Sea environment to

1 See: "Environmental history on the Internet": http://www.cnr.berkeley.edu/departments/espm/env-hist/eh-internet.html#intro.

2 S. Pyne (2005), "Environmental history without historians", 73. Prof. Pyne is one of those historians who, due to his occupation as an Environmental historian, had to change faculties and moved into the School of Life Sciences (SoLS), specifically a Human Dimensions Faculty (the Lost SoLS); in Israel, only last year a call for scholars of Humanities and Science to regroup for discussions on promoting environmental history studies was initiated.

the political, economic and cultural history of the people around its coasts and deep in the hinterlands of the surrounding continents. In this opera, Braudel mainly related to the sixteenth century with sporadic glimpses to the late Middle Ages, on the one hand, and on the other, to the seventeenth century.[3] In his second work, *Memory and the Mediterranean*,[4] Braudel discussed the Ancient world, beginning in the Paleolithic Age. Only at the end of the twenties century another opera, following Braudel's pioneering work and multidisciplinary methodology, was written on the Mediterranean and the Black Sea. Written by Peregrine Horden and Nicholas Purcell and entitled *The Corrupting Sea: A Study of the Mediterranean History*, this new and very controversial work, published in Malden, Massachusetts in 2000, includes immense learning and resolute up-to-dateness of Braudel's work.[5] Nevertheless, both Braudel and Horden-Purcell dedicated only small percentage of their work to marine environment and resources. Braudel takes as a fact that except of the lagoons "the Mediterranean waters are hardly more productive than the lands. The much wanted *frutti di mare* (seafood) are only moderately abundant...the scarcity of fish explains the scarcity of fishermen and consequently that of sailors". According to Braudel that was the source of problem of shortage of manpower to work on ships, which eventually lead to employment of prisoners of war and convicts as rowers on the war galleys of the mid-sixteenth century.[6] Indeed, fishery historians, whose expertise is either ancient and early Middle Ages or the early Modern period, followed Braudel claim that no marine fishing was available in the medieval Mediterranean, but only at lagoon or the rivers' mouth.[7]

A similar approach was adopted by Horden and Purcell, who claim that "even after the advent of steam and diesel engines made catching deep-sea fish safer than ever before, they remain unimportant for Mediterranean diet". Most of the fishing in historical period was in lagoon waters and at the mouth of rivers towards the sea.[8]

It should, however, be pointed out, that Henri Bresc proved the continuity of marine fishing through the Middle Ages in the Western Mediterranean and quite recently (2006), Gertwagen did the same regarding the Medieval and early Modern eastern Mediterranean, while discussing the marine environmental history of those period in this area.[9]

---

3 F. Braudel (1972), *The Mediterranean*, New York.

4 Id., (2001), *Memory and the Mediterranean*; originally the book was supposed to be published in the early 1970s, as the manuscript had been sent to the Publishing House in 1968; due to various circumstances, discussed by the "Editors' Forward to the French Edition", pp. xxiii-xxxiv, the book was published in French in 1998 and translated into English in 2001.

5 On part of the hard critics against this work one can learn by Horden's and Purcell's responses: P. Horden and N. Purcell (2005), "Four Years of Corruption", pp. 349-375; the various chapters of the book also relate critically to Horden's and Purcell's book.

6 Braudel (1972), *The Mediterranean,* pp. 138-9.

7 Regarding historians dealing with pre-medieval period, see: below n. 24. Regarding historians dealing with the modern period, see: Maria Lucia De Nicolò (2008), "Il pesce nell'alimentazione mediterranea (secc. XVI-XIX)", pp. 35-45 with relevant bibliography.

8 Horden and Purcell (2000), *The Corrupting Sea*, pp. 190-2; and see in index values "fish", "fishing".

9 H. Bresc (2001), "*Pêche*", 525-539 and ns. 1,3; R. Gertwagen, "*Approccio multidisciplinare*", 144-182.

It should be also noted that in J. Donald Hughes book, entitled: *Nature and Human Societies, The Mediterranean An Environmental History*, Published in 2005 in Santa Barbara, California, Denver, Colorado and Oxford, England, fishing occupies a very small percentage as well.

What is marine historical ecology?

Marine historical ecology focuses on detecting patterns of long historical changes and fluctuations in various marine species composition, stock size and ecosystems due to anthropogenic intervention: overfishing, habitat disruption as a result of land-use reclamation and fishing disturbance, eutrophication, pollution, introducing alien species through ship ballast, as well as, due to ecological impacts such as climate change and invasive species. The marine historical ecologists aim to look for the earliest data possible – to establish a baseline - on beginning of human exploitation of marine animal populations and impact on oceans ecosystems *vise a vise* climate impact; in other words, to compare the status of an impacted system with that of an un-impacted, thus to evaluate stock economic losses, the current state of marine ecosystems, in order to make future projections and identify targets for rehabilitation measures. The data used are provided by various historical documentations, archaeology, zoo-archaeology and art evidence, anecdotal and Anthropological and genetic evidence.

Two papers relating to historical marine ecology are noteworthy. One is of John K. Pinnegar and Georg H. Engelhard (2007), who discuss the importance of shifting the baseline backwards as much as possible, while stressing the mistakes done so far mainly in the projection area by modeling only using the last thirty years data. The authors discuss the multidisciplinary sources of data to be used, while pinpointing to the problems involved. They also indicate the importance one should give to differencing between or to the correlation between historic anthropogenic and climatology impact on various species and ecosystems.[10]

The second paper that should be consulted was published in 2009 by Heike K. Lotze and Boris Worm concerns the implementation of finding the shifted backwards, as much as possible, baseline, focusing, however, on human impact, consciously separating it from environmental - climate impact. The paper synthesizes patterns of long historical changes in large marine mammals, birds, reptiles mainly in vast regions in the Atlantic, Indian and Pacific Oceans, as well as, in the Baltic Sea and Europe. The authors used data derived from multidisciplinary fields: paleontology, archaeological evidence, molecular markers, historical records and fisheries statistics to extract quantitative estimates for measuring and interpreting those long-term changes, thus to produce a global general picture of historical baseline.[11]

---

10 J.K. Pinnegar and G.H. Engelhard (2007), “The ‘shifting baseline’”, 1 – 16; D. Pauly (1995), “Anecdotes and the shifting baseline syndrome of fisheries”, 430.

11 H.K. Lotze and B. Worm (2009), “Historical baselines", pp. 254-262; both authors are of the biology Department in Dalhousie University.

Both papers were written by scientists, who used historic documentation and the various archaeological and zoo-archaeological evidences as sources for hard data for the only purpose of finding the earliest baseline ever for impacted species and ecosystems. For Lotze and Worm, who make part of the framework of another arm of Census of Marine Life, the Future of Marine Animal Populations (FMAP) global project, these data are essential also for future projection based on modeling. The methodology of marine historical ecology focuses on the statistical modeling of the effects of fishing, climate change and other key variables on the above-mentioned synthesized globally changing patterns derived from biological data (http://www.fmap.ca/index.php).

Methodically speaking, marine scientists or ecologists examine each discipline separately for data, however without verifying their authenticity and historic context. Historic context in a vast term means, among others, to identify the writer of the document and the historic environment he wrote it; is the document original or a copy; is the document a product of hearsay or of eye witnessing etc. Indeed, as Lotze and Worm declare right at the beginning of their paper: "the value of using a diversity of data sources for historical studies has been reviewed elsewhere",[12] i.e. marine nvironmental history. **The methodology that the marine historical ecology uses is called multidisciplinary**.

It should, however, be pinpointed that using data without verifying their authenticity and historical context would lead to mistakes in interpretation and, eventually, to false data for modeling, projection and to false data to contemporary managers charged with rebuilding depleting stocks of fish and marine mammals. The following example would illustrate the argument regarding against taking data on their face value.

196 fish bones of grey triggerfish *Balistes carolinensis* (= *capriscus*) were found at Atlit Yam, the submerged fishing Neolithic village of the 7th and early 6th millennia BC, the early Holocene period, along the Israeli coastline. The site that seems at present one-phase settlement was abandoned due to sea level rise (10000 – 8000 BP). The *B. carolinensis,* whose remains make 92% of total fish bones found in the site, that provided up to 15% of the daily protein requirements of the inhabitants and that contributed to the subsistence economy of the site, is a predatory fish inhabiting sands and rock bottoms of the sea, 10 to 100 m deep. Other evidence of the site, like tooth analysis of the skeletons found, suggest fishing occupation, including off shore deep-sea fishing, alongside cattle growing and agriculture.[13] The wide ranges of estimated body mass (90-3400 g) and standard length (100-450 mm) of triggerfish at Atlit Yam indicate intensive fish exploitation regardless of individual size. The same pattern was observed in another Neolithic site, Cape Andreas Kastros in Cyprus, that also reveled abundance of grey triggerfish remains that imply to the significant economic value of this specie also in this site as well as it might have been in other prehistoric Mediterranean coastal sites. The *B. carolinensis* is found today throughout the Mediterranean and Black Sea, including the coast of Israel.[14] This means that the

12 *Ibid.*, p. 254.

13 E. Galili, M. Weinstein-Evron, I. Hershkovitz, A. Gophen, M. Kislev, O. Lernau, L. Kolska-Horwitz, and H. Lernau (1993), "Atlit Yam", 133-157.

14 I. Zohar, T. Dayan, and E. Spanier (1997), "Predicting Grey Trigger fish body size from Bones", 150-156.

present ecological conditions in the Mediterranean are not sharply different to those that prevailed in the Neolithic period, albeit the climatic changes i.e. the above-mentioned global warming that caused to the sea level rise and to the submergence of the Atlit Yam site. **Nevertheless**, according to sources provided by Agricultural Organization of the United Nations and the Department of Fisheries, the Israel Ministry of Agriculture, the total annual current yield of Eastern Mediterranean (the Black Sea excluded) triggerfish fisheries is only ca. 1%. According to interviews with fishermen along the Israeli coast this species has a very low economic value. In the Past it was more important.

To only take these data on their face value, one could erroneously point higher abundance of this species in the past along the Eastern basin, hypothesizing as the reason for the current scarcity of this species overfishing, although for reaching such a conclusion, one should detect the history of this fish through long historic periods.

However, this crude interpretation needs additional questions to be addressed, among others, change of taste habits or health awareness of the population. Indeed, the *B. carolinensis* “is widely considered inedible among Mediterranean populations and according to interviews with fishermen along the Israeli coast, nowadays this species has a very low economic value”.[15]

It should be also stressed that, quite often than not, the more expanding ecological timelines into the past less quantitative data are available *vise a vise* qualitative; as well as one should expect gaps in information in terms of geographic spaces and of periods, certainly while talking globally, but also “regionally” like in the Mediterranean and Black Sea.[16] Aiming, therefore, to global historic generalizations, would also lead to false interpretations. Modeling would, undoubtedly, have to be adapted to meet these gaps.[17]

Furthermore, since ecologists aim to heal and restore depleted stocks including providing data, modeling would merely illuminate problems but not solve them realistically, as that can only be done by the human being himself and the whole society. Ecologists have, therefore, to think historically or to collaborate actively with historians to ask other questions, beyond requiring hard data regarding: “what”, ”how” and “when” did the mankind do and cause. One of the other questions that should be explored is **“why”** did mankind treat the oceans and the marine animal populations as he did, and was there any intentional “governmental” policy behind. Moreover, since one of optimistic roles of history is to avoid mistakes or harms done in the past, ecologists should thrive to explore historically, if there have been any indicative or repeated patterns for human impact, either negative either positive, on marine animal populations since pre-historic and historic periods that can be used as lessons to learn or implement at present and in the future.

---

15 *Ibid.*, p. 150.
16 R. Gertwagen (2008), *“Conclusioni del Workshop”,* p. 210.
17 See discussion on this issue by S. Libralato, D. Melaku Canu, and C. Solidoro (2008), *“Bridging Gaps",* pp. 202-9.

What is marine environmental history?

Marine environmental history shares identical aims of the marine historical ecology and more; Marine environmental history reaches, however, these goals by examination of the long historical reciprocity relationships between the society as a whole and the human being in particular and the marine animal populations and the oceans in every period and region. Marine environmental history uses the same multi disciplines as marine ecological history, however, analyzes them in historic context and employs them **interdisciplinary, i.e. in a way that they contemplate, illustrate and clarify each other;** thus to get also a holistic picture on other aspects of human environment interactions such as: economic, politic, anthropological, cultural, etc.

In his review article, "Opportunities in Marine Environmental History" – that follows the evolvement and importance of the relatively young field of marine environmental history, W. Jeffrey Bolster, who originally is a maritime historian that broadened his occupation in the framework of HMAP to marine environmental history, talks in detail on this nascent discipline. Bolster argues that essential part in illuminating the long historical impact of human involvement in marine ecosystem is to describe long time changing nature of marine environments in which contradictory human aspiration, values, behavior, culture and constitutions, while pointing to the importance of marine resources in historical development of human society, play central roles. Historians, however, should emphasize that "complex variables create historically specific situations – no universal ones, or replicable ones, or natural ones, but specific situations". Thus marine environmental historians could enrich the information yielded by marine historical ecologists and would contribute to insight in to current patterns of human involvement in marine environment, which by itself is essential for future management. Furthermore, by historicization of the oceans, i.e. "by considering the living oceans as a dynamic player in human dramas could generate significant contributions to what we know about people as ecological actors". Since, as above-mentioned, as far back as one can shift the baseline less quantitative data are available, "historians can prove magnitude environmental change, reminding politicians and managers of the world we lost". Historicization of modeling should, accordingly, be adapted.[18]

One could argue that the different approach of historians and ecologists/scientists to historical issues on marine environment, although history is the common denominator, is conspicuous in terms of goals, questions asked, in employment of historical sources and data, in language used, in terms of displaying the final products and eventually in terms of self definition. Moreover, marine historians and marine ecologists, according to Bolster, share fundamental conceptual disagreements about the relationship of the past to the present and future. Richard Hoffman, a prominent environmental historian of the Middle Ages with a sound expertise in ecology, as well as, the leading authority on fish culture and fishing in Medieval Europe, claims that due to natural scientists' commonly

18 W.J. Bolster (2006), "Opportunities in Marine Environmental History", 567-597; on p. 589 Bolster introduces himself. See also: http://explore.noaa.gov/abstract-and-bio-history-of-marine-animal-populations-dr-jeff-bolster.

lack training to find or interpret characteristically fragmentary data from the past results in the false assertion that no science means no change. He illustrates his argument with an example regarding the Rhine salmon fishery. According to one fisheries manager the Rhine salmon fishery remained unaffected by human activity up to the eighteenth century on grounds that scientific observations showed a large decline during industrialization in the nineteenth century. Hoffman argues that at best, this manager's statement encourages self-defeating acquiescence in ignorance.[19]

These different approaches, one should add, are not limited to the maritime field but are generally common between ecologists and historians regarding historic environment. Steve Pyne, in his paper "Environmental history without historians", defines these differences clearly: "By training and temperament, scientists are problem-solvers. Academic historians are problem-illuminators, although they seem to pride themselves recently on being simple problematizers. The sciences are moving rapidly toward multidisciplinary collaborations; they enthusiastically team-teach; they are willing to include within their congregation whoever might contribute. **What they hope to get, especially, is help on data, policy, and ethics. How this contributes to history *qua* history, they care little, any more than historians might fret over the complexities of Bayesian statistics**".[20]

Nevertheless historians don't have the monopoly on marine environmental history nor on marine ecological history, albeit their professional skills to use the diversified historic tools and their interpretation, unless they have the appropriate education regarding basic fish biology, distribution and behavior; in other words, in marine ecology and environment disciplines and their sub-fields. Historians, who are newcomers to marine ecology and environment, have to collaborate with marine ecologists to understand the ecological and environmental information provided by the various historical documents, beginning with ecological and environmental basic terminology: understanding a common language is definitely a substantial forward step to bridge over gaps. Quite often than not a term of a certain marine animal in one place is not identical to another in a different place in the same marine zone. The historian could certainly use collaboration with the ecologists to verify the authenticity of various marine animal populations displayed by diversified archaeological and artistic evidence, to identify those marine animal populations, their place of origin; or to recognize the various fishing gears and the species they were destined for etc.; historians need ecologists, oceanographers and climatologists to understand the impact of climate upon rivers and sea salinity and fisheries. Historians undoubtedly need ecologists to provide the final products that detect and reconstruct long-term changes in marine biodiversity and ecosystem since remote historic periods, in order to implement healing measures and recovery plans for depleted marine ecosystems and species and for recommending measures to avoid future such damages.

The paper, entitled: "What can fisheries historians learn from marine science? The concept of catch per Unit effort (CPUE)", written by René Taudel Poulsen, a scientist, and by Poul Holm, a marine environmental historian and, in fact, head of HMAP global project, provides another aspect of scientists' contribution to historians. The authors argue in

---

19 R.C. Hoffman (2008), "Medieval Europeans and their Aquatic Ecosystems", p. 47.

20 S. Pyne (2005), "Environmental history without historians", p. 73.

favor fisheries historians' adaption of the CPUE analytical tool employed by marine scientists, to lend methodological coherence to an historical analysis of fluctuations of fisheries. The authors claim that the CPUE analytical tool can be used by fisheries historians for at least two purposes. First, as a useful indicator to assess the performance of fisheries. The second purpose is to reveal changes in the abundance of the fishermen's target species. The authors illustrate their assertions with an example from the nineteenth-century Swedish North Sea fisheries for ling, cod and tusk.[21] Nevertheless, it should be pointed out that Taudel Poulsen's and Holm's arguments are only valid for those historic periods in which quantitative data are available. As, however, it has already been discussed above, the more expanding ecological timelines into the past less quantitative data are available *vise a vise* qualitative.

Fundamental conceptual disagreements about approaches and the relationship between various sub-disciplines, one should point out, are not limited to detached fields like Science and Humanities, but exist inside each of Humanities and Science disciplines as well. For instance, there is fundamental conceptual disagreement between historians and archaeologists regarding interpretation of the past that, among others, is derived from using different language and in a way, from intentional miscommunication, due to pride.

Historians argue against archaeologists, as they do against scientists involved in historic research, that they use historic evidence without verify their authenticity and historical context. They only apply to history, as the archaeologists themselves admit, to support their material evidence. When, however, the archaeological remains are not in agreement with the historical records, historians argue justifiably that archaeologists ignore the historic evidence and create their own history. Quite often than not, misunderstanding the historic documentation, the archaeologists end, although unintentionally, with destroying the archaeological remains or with inventing, among others, material historic reality (such as urban spaces or architecture of building etc.) that did not exist in historic periods. Such crucial mistakes have severe bearing on reconstruction of various archaeological remains and on developing policy of archaeological sites. Furthermore, archaeologist tend to interpret historical reality only based on their own site and not in relation to other contemporary sites in the same wide geographic zone, like the whole Mediterranean.[22]

Archaeologists argue that material remains are hard data to and cannot be contested against, even if they are not in agreement with historic evidence. Rather, the archaeological remains should be treated as historic reality. Furthermore, they argue that historians

---

21 R. Taudel Poulsen and P. Holm (2007), "What can fisheries historians learn from marine science?", 89-112.

22 R. Gertwagen (2000), "The concept of ports", 177-181; In these pages the author methodically discusses the disciplines that should be involved in the study of medieval ports and their interdisciplinary employment: history, geography, geology, oceanography and marine engineering (regarding ports and the various ships of the period), urban architecture and archaeology and marine and underwater archaeology. The author has academic background for these disciplines and employs the multi and interdisciplinary methodology in her current research activities. Gertwagen points to focal mistakes done by underwater archaeologists misusing historical documentation, or by historians unable to verify archaeological results, due to lack of the technical language that consequently lead them to interpret documents to agree with the archaeological data, and the bearing of these faults by both archaeologists and historian on developing policy of medieval ports.

use archaeology only as a subsidiary discipline to illustrate historical context when it suits their purposes. Archaeologists, it should be added, do not view themselves belonging to pure Humanities since they use scientific methods such as: statistics, physics and chemistry for dating and material analysis, anatomy, medicine and anthropology for analysis of human skeletons, biology and zoo-archaeology for fauna remains, geography, oceanography and environment etc. In fact, they consider their presence in the Humanities Faculty in the various Academic institutions as *archaic*. Quite often than not archaeologists publish in different academic journals than Humanities, using the methods of citations and notes employed by the science discipline. Such an attitude undoubtedly increases the basic conceptual gaps between archaeologists and historians.[23]

Discussions through e-mail correspondence between the summer school's attendants from the Science discipline prove, however, to miscommunication and disagreements between the various disciplines of Science as well. Arguments were made by students and the answers or contra-arguments were made by an ecologist and environment historian, Prof. Fernando Boero, who was one of the lecturers in the summer school.

An M.A. student of oceanography indicated that that his professor of Physics at the University stated that all disciplines whose name ended with the suffix "*ica*" (*Fisica, Chimica, Matematica* and *Statistica* – Physic, chemistry, mathematic and statistic) are "hard sciences", and conversely, other fields, such as ecology, biology, etc. are considered "soft sciences". These "soft sciences" are not important and not worthy for study by their own merits by those specializing in "hard sciences".

Boero divided his answer into two parts. He first rejected the above-mentioned approach, claiming that since life is the most complex in the known universe, then biology and ecology disciplines, occupied with life, study the most complex phenomenon of the known universe. His conclusion as an ecologist is that exactly those sciences that label themselves as "hard" deal in fact with the simple phenomena. This includes mathematics – modeling- which is useless for complex studies like history; he also claims that the above-mentioned physician argument is a result of vanity and ignorance of biology and ecology disciplines. The next part of Boero's reply related to the scientists' view of the modeling as a predicting tool. He first rejected science's role as a mere predictor. Science is essential to understand patterns and processes of occurrence, behaviors etc. Then the scientist can make predictions by using modeling, however with great caution, taking in account irregularities that cause to changes, since irregularities happen inevitably. Therefore, if not all variables and the links connecting them are considered in the model, it is irrelevant.

Boero also rejected the argument made by another attendant of the science discipline that modeling is an essential tool for understanding ecological and biological complex systems, including their abnormalities, since modeling concerns the mental processes that lead to comprehension of the mechanism inside a phenomenon. Boero claims that models are not tools for understanding or for gaining further insight, since they only help to introduce all phenomena under discussion, to formalize what one knows, and work by

23 Gertwagen's personal communication. As an historian with education in archaeology and being a pioneer of medieval archaeology in Israel, Gertwagen expresses this paragraph based on her own experience and discussions with her archaeologist colleagues.

correlating factors. Models, however, Boero pointed out, are not conducive to identify the actors or the causations.
These exchange of all views discussed above pinpoint the importance of our summer school, whose one of major goals was to bring together scholars of Humanities and Science, and vice versa, to provide as much as possible a better understanding of each discipline's and sub field's languages, needs and potential to bridge over the gaps between Humanities, environmental and ecological approaches and between their sub-disciplines. By itself this aim should not be treated as too ambitious, if one looks at the initial steps towards bridging over gaps, taken by prominent historians, who acknowledge the necessity to change attitude from the traditional one towards using science in addition to archaeology in order to understand how life, in the wide spectrum of the term, were in remote historic periods. The pioneer is the above-mentioned Richard Hoffman, who is the leading marine and fresh water environment and ecology historian of Medieval Europe. Michael McCormick of Harvard University, whose expertise is Late Antiquity, Early Middle Ages and Byzantium economy, is another one. He is currently working on natural scientific approaches to the ancient and early medieval past, including the history of human health and the environment. Two papers of his are indicative in this respect, since they have also bearing on marine environmental history and ecology as they, among others, address question such as, what was the people's of those period diet, how much did they eat, where did they come from etc. In one of the papers he appears as a solitary compiler and it is methodological: M. McCormick, "Molecular Middle Ages: Early Medieval Economic history in the Twenty-First Century" in The Long Morning of Medieval Europe. New Directions in Early Medieval Studies (eds.), Jennifer R. Davis and Michael McCornmik, Britain, Ahsgate, 2008, pp. 83-98. In the second paper, McCormick collaborates with other scholars of different disciplines: M. Salamon[a], A. Coppa[b], M. McCormick[c], M. Rubini[d], R. Vargiu[b] and N. Tuross[a][24], "The consilience of historical and isotopic approaches in reconstructing the medieval Mediterranean diet ", Journal of Archaeological science, vol. 35, issue 6 (June 2008), 1667-1672.
Although the validity of the historic conclusions, emphasizing the cheap import of Atlantic cod into the Mediterranean as early as the 14th century, could be questioned, this paper is a good example of fruitful collaboration between Humanities and Science. Considering that the historian's expertise is Late Roman and early Middle Ages, and the case study deals with the Late Medieval period, this paper provides a good lesson that historians specializing in a certain period should deal with the scientist results related to their historic specialization to avoid wrong vast spectrum conclusions.[25] Nevertheless, as an econo-

24 a. Department of Anthropology, Harvard University, 11 Divinity Avenue, Cambridge, MA 02138, USA; b. Dipartimento di Biologia Animale e dell'Uomo, University of Rome La Sapienza, Piazzale A. Moro, 5, Rome I-00185, Italy; c. Department of History, Robinson Hall, Harvard University, 35 Quincy Street, Cambridge, MA 02138, USA; d. Soprintendenza per i Beni Archeologici del Lazio, Servizio di Antropologia, via Pompeo Magno 2, Rome I-00193, Italy.
25 McCormick used Braudel's statement on the poverty of the Mediterranean, in contrast to the Atlantic, in marine resources as a starting point; then he continued to the evidence on the northern Europe's economic and demographic growth beginning around 1000 AD that fueled an expansion of the food supply and market economy from industrial-scale fishing in the Atlantic. Nevertheless, Braudel, as above-men-

mist historian, prof. McCormick undoubtedly paves, by his studies, the way for other historians to step outside the conservative box of dealing with the history discipline.
One could not phrase it better than the late Angeli E. Laiou, another leading economic historian whose expertise was the Byzantine period that said: "Since the scientific fields involve biology, genetics, physics, move at fast pace, the challenge for younger generation of historians will be to master, or at least have a very close acquaintance with, ever-refined techniques, while at the same time acquiring firm foundations in the traditional tools, such as philology, archaeology and textual analysis".[26]
The same should, undoubtedly, be applicable for scientists and archaeologists dealing with historic periods, i.e. full collaboration with historians, beyond considering Humanities as only as providers of hard data. For marine ecologists and environmentalists, whose aim is to heal the long *durée* damages caused to the Oceans and the marine animal populations since pre-historic and historic periods, such collaboration is essential, say the least.

Bibliography

Bolster W.J. (2006). "Opportunities in Marine Environmental History", *Environmental History* 11: 567-597.

Braudel F. (1972). *The Mediterranean and the Mediterranean World in the Age of Philip II*, New York.

Braudel F. (2001). *Memory and the Mediterranean*, text edited by Roslyne deAyala and Paule Braudel, translated from the French by Siâ, Reynolds, New York.

Bresc H. (2001). "Pêche et habitat en Méditerranée occidentale", *Castrum* 7: 525-539.

Galili E., Weinstein-Evron M., Hershkovitz M., Gophen I., Kislev A., Lernau M., Kolska-Horwitz O.L. and Lernau H. (1993). "Atlit Yam: A prehistoric site on the sea floor off the Israeli coast", *Journal of Field Archaeology* 20, vol. 2:133-157.

De Nicolò M.L. (2008). "Il pesce nell'alimentazione mediterranea (secc. XVI-XIX)", in *Il mare. Com'era*, cit., pp. 35-45.

Gertwagen R. (2000). "The concept of ports in the Medieval Eastern Mediterranean: Construction and maintenance on Crete to the end of the fifteenth century*", International Journal of Maritime History* 12, No. 1: 177-241.

Gertwagen R., Raicevich S., Fortibuoni T., and Giovanardi O. (Eds.) (2008). *Il mare. Com'era. Le interazioni tra uomo ed ambiente nel Mediterraneo dall'Epoca Romana al XIX secolo: una visione storica ed ecologica delle attività di pesca. Atti del Workshop internazionale HMAP del Mediterraneo e Mar Nero Chioggia, 27-29 Settembre* 2006, ISPRA, pp. 224.

tioned, did not deal with the Medieval Mediterranean. Furthermore, McCormick ignored the regular navigation line from the Black Sea, conducted by Genoa and Venice, that imported to Southern and Western Europe caviar and salted fish. The whole historic conclusions, regarding the early imports from the Atlantic into the Mediterranean: "The increased consumption of marine resources observed in the individuals from Rome [in the late Middle Ages] may offer the first physical evidence of this new economic reality linking the Atlantic and Mediterranean economies at the end of the Middle Ages" should be, therefore, reconsidered; It is, however, beyond the scope of the present paper.
26 Angliki E. Laiou (2008), "The Early Medieval Economy", p. 99.

GERTWAGEN R. (2008). "Approccio multidisciplinare allo studio dell'ambiente marino e della pesca nel medioevo nel mediterraneo orientale" in *Il mare. Com'era,* cit., pp. 144-182.

GERTWAGEN R. (2008). "Conclusioni del Workshop" in *Il mare. Com'era*, cit., pp. 210-214.

HOFFMAN R.C. (2008). "Medieval Europeans and their Aquatic Ecosystems" in *Beiträge zum Göttinger Umwelthistorischen Kolloquium 2007 – 2008*, (Ed.) B. Herrmann, Universitätsverlag Göttingen, pp. 45-64.

HORDEN P. AND PURCELL N. (2000). *The Corrupting Sea: A Study of the Mediterranean History*, Malden, Massachusetts.

HORDEN P. AND PURCELL N. (2005). "Four Years of Corruption: a Response to Critics" in *Rethinking of the Mediterranean* (Ed.) by W.V. Harris, Oxford, pp. 349-375.

LAIOU A.E. (2008). "The Early Medieval Economy Data, Production, Exchange and Demand" in *The Long Morning of Medieval Europe. New Directions in Early Medieval Studies* (Eds.), J.R. Davis and M. McCornmik, Britain, Ahsgate, pp. 99-104.

LIBRALATO S., MELAKU CANU D. AND SOLIDORO C. (2008). "Bridging Gaps: Utilità dei modelli e di altri metodi numerici per l'analisi dei dati storici" in *Il Mare. Com'era*, cit., pp. 202-9.

LOTZE H.K. AND WORM B. (2009). "Historical baselines for large marine animals", *Trends in Ecology and Evolution* 24, No.5: 254-262.

PAULY D. (1995). "Anecdotes and the shifting baseline syndrome of fisheries", *Trends in Ecology and Evolution* 10: 430.

PINNEGAR J.K. AND ENGELHARD G.H. (2007). "The 'shifting baseline' phenomenon: a global perspective", *Reviews in Fish Biology and Fisheries* 18: 1–16.

PYNE S. (2005). "Environmental history without historians", *Environmental History* 10, Iss. 1: p. 72-74.

TAUDEL POULSEN R. AND HOLM P. (2007). "What can fisheries historians learn from marine science? The concept of catch per Unit effort (CPUE)", *International Journal of Maritime History* 19, No. 2: 89-112.

ZOHAR I., DAYAN T. AND SPANIER E. (1997). "Predicting Grey Trigger fish body size from Bones", *International Journal of Osteoarchaeology* 7: 150-156.

ROMAN FISHING TECHNOLOGY IN CONTEXT

Tønnes Bekker-Nielsen
University of Southern Denmark, Kolding (Denmark)
e-mail: tonnes@hist.sdu.dk

Key-words: *fishermen, garum, gastronomy, Edict of Diocletian, Apicius*

Over the last two decades, our knowledge of Roman fishing has increased dramatically. Applying the combined insights of biology, history and archaeology to a diverse range of pictorial, literary, archeo-zoological and archaeological materials, it has been possible to establish a comprehensive picture of Roman fishing as a diverse and sophisticated industry – very different from the dismal image of ancient fishing presented by T.W. Gallant twenty-five years ago (Gallant, 1985). We can now state with certainty that the Romans had at their disposal every type of fishing gear known today with the exception of the trawl; that vessels were built specifically for fishing, including boats with well-boxes for keeping the catch alive (Boetto, 2006); that Romans were able to preserve the catch by a variety of techniques still used today such as dry-salting, pickling and drying, possibly – though this is not securely attested – also smoking (Højte, 2005), as well as fermenting it to produce the famous fish sauce known as *garum*.

Yet while such insights are impressive in their own right, they provide only part of the answer to the larger question concerning HMAP, anthropogenic impact on fish stocks. To establish that a given technology existed at a given date is not to say that it was actually applied. To take two modern technologies as examples, consider solar electricity generators and nuclear weapons. Solar panels provide cheap electricity in many parts of the world, though not in my native country, where there is too little sunshine. Numerous nations today possess the technology required to produce nuclear weapons but for political or, if you will, moral, reasons the weapons cannot be used. In antiquity, the application of fishing technology was likewise governed by geographical, climatic, economic, social and even moral considerations.

1. To contextualize technology, let us start with examining the people who operate it. What was it like to be a fisherman in the Roman world? In the comedy *Rudens* written in the third century BCE, Plautus gives us a stark description:

> "It is hard to be poor, especially when one has no profession and has learned no trade. (…) From our garb, you can clearly see how wealthy we are. These hooks, these rods are our livelihood and our shelter. Each day we come here from the city to the sea to seek our meagre income, the sea serves as our *palaestra* and *gymnasium,* where we go to find sea-urchins, rock-mussels, oysters, limpets, cockles, sea-nettles, sea-mussels and spotted crabs. After that, we fish with the hook and among the rocks, and thus we take our food from the sea. If success does not smile upon us, and no fish are caught, then, soaked in sea-water and thoroughly drenched, we slink home and go to sleep hungry" (*Rudens*, Act 2, 290-305).

For these men, fishing is a full-time occupation, not undertaken on the side or as a last resort. They work all day; in their lives, the sea substitutes for the *gymnasium* and *palaestra*, places where leisured gentlemen might spend their time. To what extent Plautus' world reflects the social conditions of his own time and place and to what extent the Hellenistic models on which his play is based, we do not know; certainly, the poor fisherman is a popular figure in Hellenistic art (Figure 1) and literature. Plautus may have assigned servile status to his fisherman because it fits the plot better, but the excursus on the stark living conditions of the fishers is not strictly necessary and would hardly have been included had it been out of tune with the reality known to Plautus and his audience (Rauh *et al*., 2008). For our purposes, the important thing is that the fishermen are found at the lowest end of the social scale: poor men living on the edge and, in some cases, slaves.

Figure 1. Statue of old fisherman. Musée du Louvre, MA 1354. Photo: Marie-Lan Nguyen/Wikimedia.

2. Once the fish have been caught, they need to be transferred from the boat to the kitchen. I have argued elsewhere (Bekker-Nielsen, 2005) that this was the primary technological constraint on ancient fishing: it limited the number of potential consumers to those living within a certain distance of a fishing port or landing-place, and it limited the range and size of the fishing vessels. These constraints could be overcome by transporting the fish while still alive, gutting the catch while at sea – for which we have no evidence so far – by drying or by salting it.

Salting fish was a familiar technology as early as the fifth century BC, when it is mentioned in Greek texts. By the first century BCE, salt fish was considered a delicacy, eaten in the highest circles and found even at the table of Queen Cleopatra, who used a Pontic salt-fish to play a trick on her lover (Plutarch, *Antony*, 29.4). Salt fish also found its way into the *De re coquinaria* of Apicius, the only cookbook to have been preserved from antiquity. In this collection of recipes for the upper-class kitchen, there are several dishes with *salsum* as a main ingredient and a few recipes for *salsum sine salso*, i.e. "mock" versions where salt-fish is replaced by hare, lamb, goat or chicken, or where spices such as cumin are used to replicate the taste of salt fish (Apicius, 9.13). Salt-fish was thus used not only as a substitute for fresh fish, but in its own right, for its value as a condiment and for its medicinal qualities (Wilkins, 2005). Salted fish had the advantage of being transportable over long distances, even from the Black Sea to Egypt, as we learn from Plutarch's anecdote. In other words, salting extended the geographical range of fish-eating.

To what extent salting extended the *social* range of fish-eating is more difficult to establish. Salted fish was cheaper than fresh fish, but how cheap? According to the Price Edict of Diocletian (c. 300 CE), where prices are given by weight, fresh fish, pork, beef and goat are all more expensive than salt-fish. There is any number of problems involved in the interpretation of the price edict, but we may safely say that salt-fish will have been within the economic range of middle-class households, though hardly that of the urban proletariat.

Instead of salting fish, one could keep them alive in a pond, creel, and basket or well-box. From about 100 BCE, fishponds became fashionable among the elite in Rome and especially at their holiday residences along the bay of Naples, which became the centre of Roman ostriculture and pisciculture. On a souvenir flask from the holiday resort at Baiae (Figure 2) the local oyster-beds are depicted as emblematic of Baiae, just as the Eiffel tower might be found on a souvenir mug from Paris. By the second century CE, the *villae*

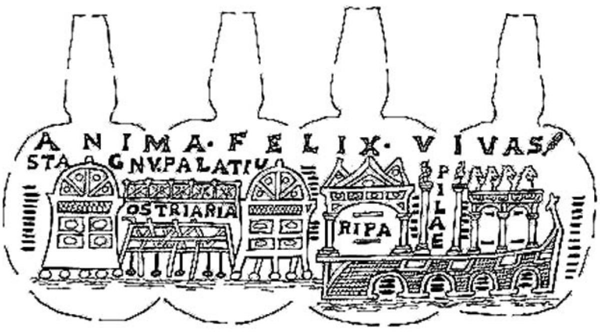


Figure 2. Roman glass flask, now in the National Archaeological Museum in Warsaw, showing the Gulf of Baiae: at left, the oyster-beds (ostriaria); at right, the pier (pilae) protecting the harbour at Puteoli.

maritimae of the well-to-do were densely spaced along the bay of Naples and the Tyrrhenian shoreline (Lafon, 2001; Figure 3), giving rise to conflicts between property-owners and the local fishermen (Digest, 1.8.4.pr.). When staying at their *villae*, many wealthy Romans would have easy access to fresh fish from their own ponds, those of their neighbours, or from the sea.

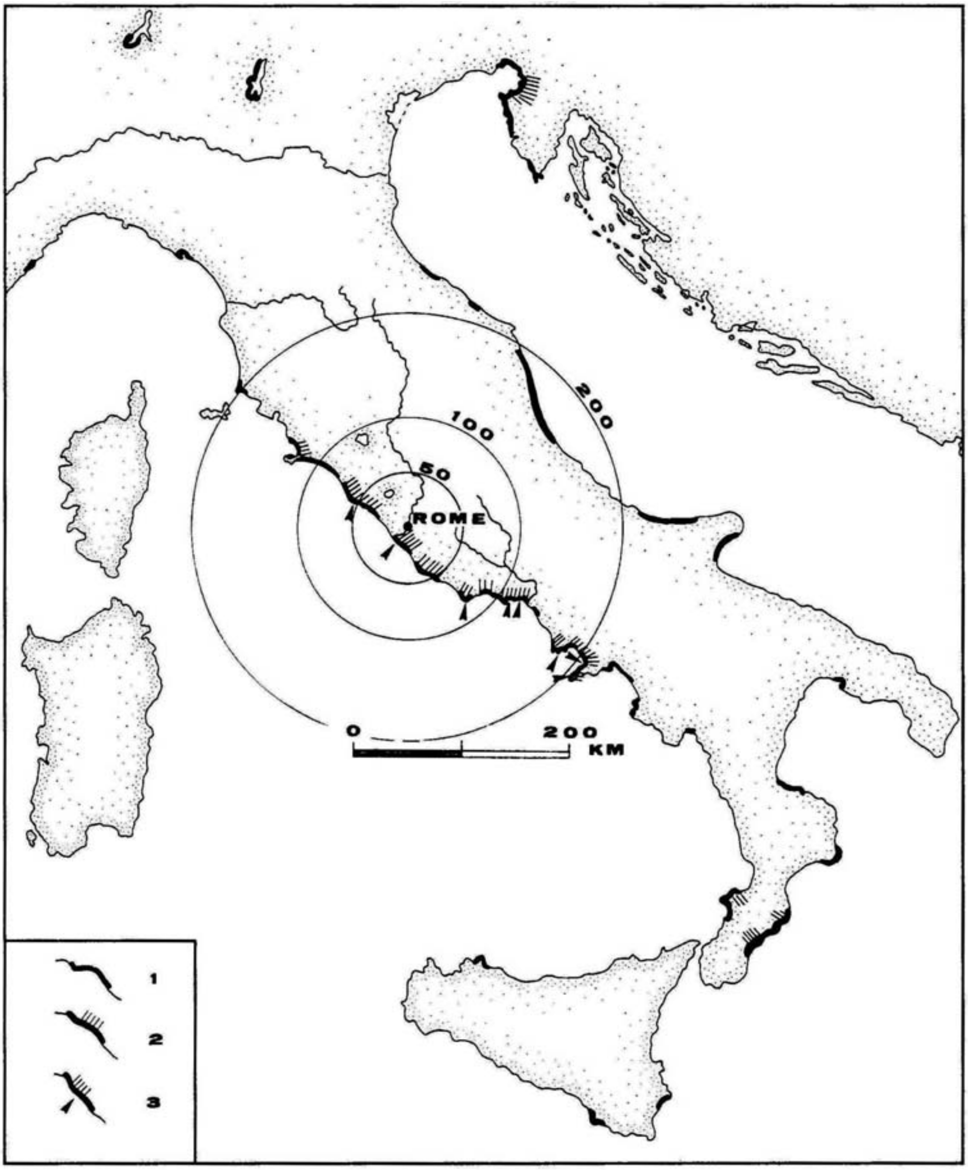


Figure 3. The density of villae maritimae along the Italian coasts, 2nd century CE. 1: more than one villa for each 10 km; 2: more than one villa for each km; 3: more than one villa per km (Lafon 2001, fig. 37).

In the first century CE, we hear of ships with well-boxes. Several sea-going vessels of this type were used to transplant a stock of parrotfish, *Scarus cretensis*, from the Aegean to the Tyrrhenian during the reign of Claudius, 41-54 CE (Bullock 2008). At Ostia, a small boat (Figure 4) with a built-in well-box (Figure 5) was found in the silted Claudian harbour (Boetto, 2006).Thus by the time of Claudius, if not before, the Romans possessed the technology to bring live sea fish ashore at Ostia and into the heart of the city. But again there is the question of context. To what extent was the technology exploited, what impact did it have on fish consumption? Although many *macella* or meat-and-fish-markets have been excavated throughout the Roman world (Ruyt, 1983), only in a few places does the evidence suggest the presence of tanks for live fish.
Certainly, the logistical problems involved in transporting live fish from Ostia to Rome were formidable. A boat journey would require at least three days from the time of catch; allowing for the return trip, a week's work for the crew was required to bring one boat-load of fish to market in the city. How much was a boat-load? In tanks, there would have to be a large proportion of sea water to fish. In well-boxes with a constant supply of fresh water from outside, more fish might be packed into the available space but the transition from the salt water of the Tyrrhenian to the fresh water of the Tiber could pose a problem. Significantly, red mullets, high on the list of luxury fish, adapt well to brackish or fresh water. Other species less suited for transport in well-boxes could be gutted and taken to market by road; a two-wheeled cart could make the journey from Ostia to the *macellum* at Rome in less than four hours.

Figure 4. Fishing boat from Fiumicino (photo: RGZM Mainz).

Figure 5. Fishing boat from Fiumicino, detail of well-box (photo: RGZM Mainz).

Technically, it would be possible to transport fish even further by cart, but the cost and the risk of spoilage increased with each additional mile. At the end of the day, the range of culinary choices was determined by economy and geography. For those living close to the shore, perhaps up to 5 kilometers from the water's edge, the cost of transport would not be an important factor; they (or their household slaves) themselves would go down to the *macellum* near the port to acquire fresh fish. This zone, which we could term "the zone of generalized fresh fish consumption", would include all cities or villages located on the coast or in estuaries. Further inland, only the wealthy minority could afford fresh fish while beyond a day's journey – 30 to 40 kilometers – from the coast, fresh fish would normally not be available at all.

3. Fish were not only consumed fresh or salted; they were also processed into *garum* or *liquamen*, a sauce made by fermenting fish in a vat for an extended time. The clear, amber-coloured liquid drawn off at the top was sometimes called *flos gari*, "flower" or cream of *garum*, the second and third qualities were of poorer quality, including an amount of solids, and known as *hallec*.

Again, context is more important than technology. The technique of producing *garum* or *garos* had been known for some time, but it is not until around the last century BCE that *garum* production on a major scale begins. The process is not complicated but requires organization, advance planning and some knowledge of the market. While *garum* could be made in vats, tubs or jars, masonry vats were preferred, and it is the remains of these vats, found from the Black Sea (Højte, 2005) to the Atlantic (Trakadas, 2005), that identify processing sites and provide an impression of the immense scale of the *garum* industry. It is very difficult, however, to make any estimates about the volume of *garum* production from the vats themselves, especially since the vats might also be used for other products such as salt-fish. It is better to compare consumption volumes with that of other foodstuffs such as wine and oil, which, like *garum*, were packed in amphorae. By comparing the numbers of amphora sherds for oil and *garum* at a number of sites in the Roman west, Ejstrud (2005) has established that on average, one liter of *garum* was consumed for every three liters of olive oil. Since olive oil was not, as today, only used for cooking, but for other purposes such as personal care and lighting, the amounts of oil consumed in a Roman household were significant and the amount of *garum*, even if only one-third that of oil, by no means negligible. In the cookbook of Apicius, the only such book to have been preserved from antiquity, *garum* is present in more than half the recipes and in almost all the sauces.

Garum was used in many Roman dishes – not only fish dishes. While Roman cooks could substitute freshwater species for sea fish or – was we have seen – sheep's livers for salt fish, no alternative to *garum* was at hand. Furthermore, *garum* production could utilize fish species which because of their size or other properties were not suitable for making salt-fish or for the table. Thus, the introduction of *garum* production on a large scale will have had significant effects on fishing strategies, which would focus more on quantity and less on selected species.

4. Our fish, in one form or the other – fresh, salted or processed into liquid – has now reached the kitchen and is ready for the dining-room of an upper-class Roman or the take-away counter in the corner *thermopolium* where most ordinary Romans obtained their

hot meal. It is time to take a look at demography, an important variable for any estimate of fish consumption and fish harvesting.
In the last two BCE, the total population of Italy may have been fairly stable, though it underwent a social polarization as the number of proletarians and very rich landowners increased while the intermediate group of small landowners dwindled. The population of Rome itself, on the other hand, grew by leaps and bounds during the same period to reach a figure of around one million under the early empire. Urban growth was driven by a variety of factors, social change in the countryside being only one, and facilitated by the predatory nature of the imperial economy, which channeled the corn tithe of the provinces into the granaries of Rome, thus keeping the price of grain and bread down.
Like their peers in other preindustrial societies, the lower classes of Rome spent a significant proportion of their income on food, and the price of a basic foodstuff like wheat or barley was a politically sensitive issue. As early as the late second century BCE, subsidized – i.e. artificially low – grain prices were used as a political weapon, and from the first century BCE, grain was distributed entirely free of charge. In the literature, this institution is sometimes referred to as the “corn dole”, but it was not a dole in the modern sense of a charitable handout to the poorest inhabitants. At one time more than 300000 citizens were eligible; even after this number had been drastically reduced by Augustus, more than 150000 remained on the list of beneficiaries. As these were not individuals but male heads of households, the proportion of Rome’s inhabitants benefiting from the corn handouts must have gone far beyond the lower classes. This is less surprising when taking into account the Roman voting system, where the votes of the *Lumpenproletariat* carried little weight. Just as in many modern welfare states, it was more politically expedient to design assistance schemes for the benefit of the lower middle classes than for the truly destitute.
Intuitively one might conclude that cheap grain would make the Roman man in the street eat more grain, porridge and bread; but a moment’s reflection reveals that the reverse is more likely. By reducing or eliminating the cost of cereals, the staple base of the diet, purchasing power would be freed for other items such as vegetables, oil, wine, condiments etc. and possibly some animal protein, widening the nutritional and culinary scope of his diet.

5. Let us stop and pause for a moment and consider the evidence at our disposal. The role of humans in the marine ecosystem is that of a predator (Stergiou, 2002). Human impact on fish stocks, i.e. the extent of human harvesting, will be dependent on two factors: the catch technology available and the size of the predator population, i.e. the number of humans consuming fish products from the sea. As we have seen, the range of techniques was more or less static throughout classical antiquity. Most fishing implements – nets, tridents, seines, etc – were known by the Classical Greek period, with the exception of the trawl. For decisive change we must look elsewhere.
From the preceding overview of the evidence, it may be assumed that given the limited size of the Mediterranean population in antiquity, human harvesting in general remained at a stable, but sustainable level – thus overfishing, while it may have taken place, will have been localized and exceptional (Ivanova, 1994; Trakadas, 2006). Taking this as our point of departure, we can identify only three events prior to AD 300 that are likely to have had

any significant overall effect on the fish stocks of the Black Sea and Mediterranean. The first is the wave of Greek colonization around 600 BCE, associated with a general increase in population *and* a relocation of population from the interior towards the coasts, thus increasing the proportion of individuals living within the "zone of generalized fresh fish consumption". A second event is the introduction of fish-salting on a large scale to the Black Sea region one or two centuries later. Both, however, fall outside the chronological scope of this paper.

The third and perhaps most important event was the introduction of *garum,* a new fish-based product that at once increased consumption of fish per capita and vastly extended the consumer population. Available in cheap as well as expensive varieties, *garum* was consumed over a much wider social range than fish. Bottled in amphorae, it could travel over long distances: in effect, as the distribution of amphora sherds demonstrates (Ejstrud, 2005) the "zone of generalized *garum* consumption" extends over the entire Empire. In turn, this increased the demand for sea fish as a raw material, and the concentration of *garum* production in certain regions of the Mediterranean (e.g., Straits of Gibraltar, Golfe de Lion-Ligurian Sea, Northern Black Sea) suggests that not all marine environments could support the massive harvesting on an "industrial" scale required to fill the vats of the fish-processing plants.

Although definite evidence is still lacking, it is likely that "industrial" fishing for the *garum* industry had a significant impact on fish stocks at the regional level, and perhaps also at the global (since the *garum* industry targeted migratory pelagic species such as mackerel).

What triggered the spectacular rise of *garum* production in the first place? For the answer, we must look to social history. Fashions in clothing, food or lifestyle are rarely autochthonous; more often, they percolate from elite trend-setters downwards through society. In the last century BCE, the senatorial elite of Rome acquired the taste for eating sea fish in their villas on the bay of Naples, and thus "fishyness", formerly been associated with lower-class people like the destitute fishermen of Plautus, acquired upper-class connotations. Inevitably, middle-class Romans wanted to imitate their superiors but faced the problem of unaffordable high prices for fresh fish. Thus, salted fish took its place in bourgeois households and the salty-fishy taste of a cooked dish became the hallmark of good middle-class cooking. When *garum* was introduced to a Roman public, everyone down to the customer at the corner cookshop could participate in the "fish and salt" experience of leading Romans, albeit in the form of fish sauce.

Bibliography

Bekker-Nielsen T. (Ed.) 2005. *Ancient Fishing and Fish Processing in the Black Sea Region* (Black Sea Studies, 2). Aarhus.

Bekker-Nielsen T. (2005). The Technology and Productivity of Ancient Sea Fishing, in Bekker-Nielsen (Ed.), *Ancient Fishing*. Aarhus, pp. 83-95.

Boetto G. (2006). "Roman Techniques for the Transport and Conservation of Fish: the Case of the Fiumicino 5 Wreck", in Hocker, F. and Englert, A. (Eds.) *10th International Symposium of Boat and Ship Archaeology*, Oxford, 123-129.

EJSTRUD B. (2005). Size Matters. Estimating Trade of Wine, Oil and Fish-Sauce from Amphorae in the First Century AD, in Bekker-Nielsen (Ed.), 171-181.
GALLANT T. (1985). *A Fisherman´s Tale* (Miscellanea Graeca 7). Ghent.
HØJTE J.M. (2005). The Archaeological Evidence for Fish Processing in the Black Sea Region, in Bekker-Nielsen (Ed.), 133-160.
IVANOVA N.V. (1994). Fish Remains from Archaeological Sites of the Northern Part of the Black Sea Region (Olbia, Berezan), *Offa* 51, 278-283.
LAFON X. (2001). *Villa maritima : recherches sur les villas littorales de l'Italie romaine (IIIe siècle av. J.-C. / IIIe siècle ap. J.-C.)* (Bibliothèque des Écoles francaises d'Athènes et de Rome, 307). Rome.
RAUH N.K., DILLON M.J. AND MCCLAIN T.D. (2008). Ochlos nautikos: Leisure culture and underclass discontent in the Roman maritime world, in R.L. Hohlfelder (Ed.), *The Maritime World of Ancient Rome* (Memoirs of the American Academy in Rome, suppl. 6), Ann Arbor, Michigan, 197-242.
RUYT C. DE (1983). *Macellum: Marché alimentaire des Romains*. Louvain.
STERGIOU K.I. (2002). Overfishing, tropicalization of fish stocks, uncertainty and ecosystem management: resharpening Ockham's razor, *Fisheries Research* 55: 1-9.
TRAKADAS A. (2005). The archaeological evidence for fish processing in the Western Mediterranean, in Bekker-Nielsen (Ed.), 47-82.
TRAKADAS A. (2006). 'Exhausted by fishermen's nets': Roman sea fisheries and their management, *Journal of Mediterranean Studies* 16: 259-272.
WILKINS J. (2005). Fish as a Source of Food in Antiquity, in Bekker-Nielsen (Ed.), 21-30.

LUXURY FROM THE SEA: PURPLE PRODUCTION IN ANTIQUITY

Carmen Alfaro Giner
University of Valencia - Department of Ancient History, Valencia (Spain)
e-mail: carmen.alfaro@uv.es

Key-words: *vegetal and animal colourings, Murex trunculus, Murex brandaris, Purpura haemastoma, Ibiza and Formentera islands*

Unde conchyliis pretia? Quis virus grave in fuco, color austerus in glaucio et irascenti similis mari
(Pliny the Elder, *Naturalis Historia*, IX, 60, 36)

Introduction: a brief look at colour in ancient societies

Just as it is today, colour was one of the most important features of ancient textiles and dress. Colour in dress helped to distinguish ages, social status and certain rituals (age rites of passage, marriage, funerals), etc. (Reinhold, 1980). In more recent times colour also marked many aspects of the life of peoples: It was easy to tell to which clan a Scot belonged by the colours of the tartan they wore. Broader social groups adopted a symbolic relation between colour and its political or religious significance. The flags and standards of the clans and the ancient *vexillationes* of the Roman army or the troops of the different Celtic peoples are good examples of the former.
The religions of many peoples used, and still use, certain colourings with particular meanings that are tantamount to language without words: the requirement of the use of white in Egyptian sanctuaries; the fine red bands that the Greeks put on the funeral monuments of their loved ones to give them strength (Figure 1); the colourful little flags on Tibetan sanctuaries with certain prayers intended to "fly" to the divinity borne along by the wind, are just some of the better known examples.
The origin of all this was most likely the elements of Nature and the way in which they were valued, for their colours, with different social and religious meanings. From prehistoric times, the use of coloured stones gradually acquired a particular meaning: they were held to furnish whoever wore them with strength, courage, protection, etc. Many of the criteria employed in valuing and conceptualising colours derive from the very old "sympathetic magic" (as old as human beings themselves). Like helps like, *similla similibus*. Ancient glyptic and its symbolism involved wisdom concerning the properties of colours in which people believed blindly. Amulets and talismans made of stones were to be found everywhere in daily life in

Figure 1. Lekytos with funerary scene. Kerameikos Museum, Athens. Photo C. Alfaro.

Roman and Mediaeval times.[1] "Primitive peoples everywhere have a marked preference for red, possibly because they generally attribute notable supernatural powers to this colour" (Brunello, 1973). It could be considered also the colour of life, the representation of blood. It expressed power, strength and health. One of the natural objects most highly valued for this reason was always intense red coral. Imitation of these colours using certain elements provided by Nature gave rise to dyeing techniques.

We have no archaeological information on the most ancient periods, but the major Mediterranean cultures, which arose in the 4^{th}-3^{rd} millennium BC (especially Egypt and the Fertile Crescent), soon mastered the technology of colour and the social and religious concepts sustaining its use gradually crystallised. In the Greek world, the Late Bronze Age (20^{th}-14^{th} centuries BC on the islands of Crete and Thera especially, left us with material remains that provide irrefutable proof of the use of colour in clothing. In the walls of Santorini, the city buried by the ashes of the volcano that destroyed the island of Thera in the 16^{th} century BC, we can admire the magnificent remains of high quality fabrics – transparent, silky, and adorned with beautiful prints or embroidery (Figure 2). There also exist from that time some small but very interesting remains of fabrics dyed with real marine purple (Spantidaki-Moulherat, in print). Greek women of the classical period are commonly

1 Wilfrid Bonser, "The Significance of Colour in Ancient and Mediaeval Magic: With Some Modern Comparisons", *JSTOR MAN (Royal Anthropological Institute of Great Britain and Ireland)*, 118, 1925, pp. 194-198.

Figure 2. Wall painting of Santorini, Thera. After N. Marinatos.

described in the written sources as spinning purple wool; this is shown very clearly on some examples of contemporary ceramics (Figure 3). In addition to being able to appreciate their exquisitely fine yarns, today, thanks to laboratory analyses, we now have knowledge of the vegetable and marine colourings with which the textile fibres were treated.

Types of analysis employed to identify purple

Where an object came into contact with purple dye –through being painted with it in the case of pottery, from having been immersed in an ad hoc dye bath in the case of textiles, or through any other means, molecules of the dye have remained present. The passage of time may have led to the colour disappearing, but some remains of the molecules will always be left. The modern systems for identifying them depend on the material on which the dye was used: purple on ceramics or terracotta needs to be analysed through electroscopy techniques, including infrared spectroscopy. Purple powder for makeup can be studied with X-ray fluorescence (1.5% dibromoindigo). Purple in frescoes (such as the Santorini wall paintings) can be identified by Raman micro-spectrometry and liquid phase chromatography. Purple on textiles from Palmyra (Syria) was analysed as early as 1934 by Pfister using reaction calorimetry. Today textiles are treated with the mass spectroscopy system. Chemical analyses can show the presence of dibromoindigotin. The molecule that reveals the presence of purple, made up of two atoms of bromine and one of indigo 6.6' dibromoindigo.

Figure 3. Alabastron. Kerameikos Museum, Athens; ca 450 a.C. Ph. C. Alfaro.

Colour and the environment

The terrestrial and marine environment in the area of the Mediterranean Sea and the Black Sea provided an enormous number of ways of achieving the desired end: transforming the monotonous colours of the natural fibres employed (flax, hemp, wool, silk, cotton, nettles, aloe, the hair of various animals, esparto grass, linden bark, marine byssus, etc.) into colourful fabrics suitable for making into clothes with their own cultural personality. Greeks and Romans personalised environmental wealth in the shape of two divinities worshipped from long ago for their generosity. These were Tellus and Oceanus, who together formed the Oecumene (Figure 4).

Many of the elements offered by nature were used to obtain colour. However, it should be borne in mind that, depending on the environment, each people tended to use the colouring items it had closest to hand and which it soon learned to master as far as technique was concerned. Hence, the great variety of possibilities that needs to be taken into account in studying ancient textiles.

The use of local plants or animals may indicate local production as opposed to imported products if a fabric that has been dyed with purple is found in an area deep inland or near

Figure 4. Augustean gemme. Kunsthistorisches Museum, Wien. After Megow.

a sea coast where there are no gastropods suitable for local output.
In Antiquity natural colours came from three sources: mineral, vegetable and animal (terrestrial and marine). In the Mediterranean and Black Sea cultures, it was mostly vegetal and animal colourings that were used to dye fibres and clothes, and the same may be said of Central Europe. A wide range of extremely beautiful hues were obtained with them and the results have sometimes survived to this day in excellent condition, although this does not apply to all of them.
The land provided the basic colours (red, blue and yellow) in its minerals and, specially its plants (Brunello, 1973). Mineral colours were not much used in the ancient Mediterranean world. However, certain minerals, such as ferruginous clay, are still employed today in South and Meso-America (by the Boruca of Costa Rica, and in Mexico, the famous *palli* described by Fray Bernardino de Sahagún in 1547). In Antiquity, certain minerals were used in small amounts as mordant in the application of vegetable dyes. These

2 Aristóteles nos informa de que, en el caso del tinte obtenido de los gasterópodos marinos, una vez extraido el glande que contenía el licor el resto del cuerpo carnoso del animal hacía el efecto de mordiente o fijador del color (*HA* V, 547a 20).

minerals caused the plants containing dye to release it and helped to fix it in the fibres.[2] Of particular use for such purposes were copper, tin and iron salts, potash and alum (also necessary for tanning hides). This latter is most commonly found in volcanic ground and was an object of maritime trade in Antiquity, Lípari, Melos, etc. (Borgard *et al.*, 2005). Pliny the Elder speaks of two kinds of alum, one white, the other black (Pliny NH XXXV, 183 s.), which was in fact iron sulphate. Greco-Roman culture also used some types of sand, although this was more for cleaning than actually dyeing: fuller's sand for cleaning cloth in the *fullonicae* (fulleries).

Concerning vegetable colours we can say that there are an infinite number of dye-giving plants (Cardon 2003; 2007). Suffice as examples three of them used for obtaining blue (*Isatis tinctoria*, L.), red (*Rubia tinctorum*, L.) and yellow (*Carthamus tinctorius*, L.). Vegetable tannins (such as those in walnut shells) were also used throughout the Mediterranean world (Pliny NH XVI, 26 s.). Sometimes vegetable dye was extracted by animals associated with certain types of tree. The clearest example is that of *Kermococcus vermilio*, Planch, which breeds in the *Quercus coccifera* L. or that of the *Kermes ilicis*, L., which lives in the *Quercus ilicis*, L. and *Quercus suber*, L. These are hemipterous insects, vegetable parasites. They exhibit a marked sexual dimorphism - unlike the males, the females are wingless and attach themselves to the tree by means of a beak or sucker (Alfaro, 1984). The authors of Antiquity were aware of the metamorphosis: Hor. Sat. II, 6, 102; Pliny the Elder, NH XXXVII, 204; Silius Italicus, XVII, 395; Martial; V, 35, 2; 23, 5; Juvenal III, 282-284; Suet. Ner., 30. However, they classified them as vegetable dyes, galls or excrescences of the Quercus family.

Fungi, lichens (the *fucus* of the ancients; our *Lichen rocella*, L.) and even some types of seaweed were used to colour textile fibres. *Rytiphlaea tinctoria* var. *horridula* J. Agardh, a red marine alga that is relatively abundant in the Mediterranean, was used to give a dark red colour very similar to Tyrian purple, as a result of which certain authors have wrongly asserted that Tyrian purple itself was made from the alga in question (Augier, 1985).

Dyes of marine animal origin: The Sea and its wealth of dyes

We know that of all the many hues that nature offered and which were reproduced artificially in Antiquity, one especially became a social status symbol. I am referring to so-called royal purple or Tyrian purple. The purple workshops eventually occupied the whole of the Mediterranean and the south coast of the Black Sea. The difficulty in making this dye meant that the price was extremely high. Only the elites could afford to use it. Paradoxically, however, although this work was idealised in mythology as a result of its invention being attributed to Hercules of Tyre (the Punic good Melkart), producing the colour was actually one of the hardest imaginable activities, as we shall soon see.

The most highly prized purple had a dark bluish, rather than red, tone. I shall speak about this later. We have abundant sources mentioning this and indicating that the use of these purple shades was forbidden to anyone other than members of the royal family of the late Roman Empire. Imitating such colours for sale to those who wanted to emulate these high-ranking social classes was also punished by law.

We are going to concentrate on the bluish-red dye obtained from a particular type of marine animal: the gastropods known as *muricidae* (Lindner, 1989). There are numerous species of *muricidae* in the world (1000 according to Lindner, 1989; illustrations of many of them are to be found also in Cardon, 2003; 2007). Some give stronger pigment shades, while others are weaker; almost pink (Naegel and Cooksey, 2002) depending on the number and concentration of the chromogenes. But we know only three species of *muricidae* present in the Mediterranean and the south of the Black Sea: *Hexaples trunculus*, L. or *Murex trunculus* (Figure 5), *Bolinus brandaris,* L. or *Murex brandaris* (Figure 6) and *Stramonita haemastoma*, L. or *Purpura haemastoma* (Figure 7). All three have a special gland on the hepatopancreas in which they store the purple dye. Already known to Aristotle and Pliny, the purple-producing gland was described in detail in the second half of the 19th century (Lacaze-Duthiers, 1859). This organ, which is a fine *lamina* and easy to remove once the animal's hard shell has been opened, secretes a darkish ink that probably has a defensive or identifying function. These animals were well studied in Antiquity by Aristotle (Keller, 1913; D'Arcy Thomson, 1947). Their present-day scientific names follow the Linnaeus classification. Highly valued and intensely used, for centuries they provided the clothes of the powerful with the most spectacular sheen, the most sought-after iridescences. The purples of the American tropical Pacific (*Purpura patulla pansa*, Gould 1853; *Plicopurpura columellaris*, Lamarck 1816) have this tone. They live in hot regions, from southern California to northern Peru (Naegel 2005) and were known and perhaps exploited in many places by the con-

Figure 5. Hexaplex trunculus from Ibiza. Ph. C. Alfaro.

Figure 6. Bolinus brandaris from Cala Olivera (Ibiza). Ph. C. Alfaro.

quistadores. Two types of *muricidae* were used in prehistoric Japan: *Papuna venosa* (Akanishi) and *Thais clavigena* (Ibonishi).[3]

The value put on purple in Antiquity

Enormous value was put on purple in Antiquity. Perhaps the reason for this should be sought in the fact that all the shades imaginable could be obtained from the humble *muricidae* (Fol, 1877; 1330). Under the influence of sunlight and the oxygen in the air, or just the latter, the liquid taken from the gland of these animals turns from its original white to yellow, green, reddish violet, blue and dark blue verging on black.

In the early studies of colours at the beginning of the 16th century (Colonna, 1616), a classification was drawn up with all the basic gamuts and from black to white. Purple dye was the only one -turning from white to blue, almost black- that gave the colours of this particular range. Behind the admiration produced by this dye may have lain certain magic-religious undertones that would better explain its use by royalty and, in modern times, the prelates of the Church. The most important thing about it was the fact that the very dark blue colour was regarded as the sum of all the other colours.

3 Colour extracted from plants and minerals played an important part in ancient Chinese and Japanese society, whereas, for religious reasons to do with the death of animals, scant use was made of purple dye extracted from marine animals. That is why the arrival of Buddhism in the first quarter of the 7th century AD reinforced the use of plants, especially *Lithospermum officinale* L. var. erythrorhizon for obtained purple colors (Yamaguchi, 2008).

Figure 7. Stramonita haemastoma from Cala Olivera (Ibiza). Ph. C. Alfaro.

Such reasoning was frequent in ancient magic (since three is a magic number and so is four, seven and nine are as well, as they encompass the other two). And the same thing was thought about certain types of white objects. A white pearl, with its iridescences of all the colours which were the basis of white, also exercised an extraordinary fascination.

The production of purple dye was one of the biggest businesses of antiquity and purple was a supreme luxury. The various shades of purple and the always surprising effects obtained on the different fibres were the basis of this luxury, displayed in complex garments in which the purple yarns were mixed with extremely fine gold yarns, the maximum beauty in clothing (Alfaro, 2005). This can be seen in samples of textiles that have been conserved (Spantidaki and Moulherat, in print; Andronikos, 1977; Cardon, 2003) and even in grandiose images of apparel stretching over a long lapse of time from Crete-Thera (Marinatos, 1984) and the court of the Macedonian kings in the 4th century BC (fabric from the tomb of Philip II in Pella) to the court of the Lower Roman Empire, with the sublime garments in the mosaics of Ravenna portraying the imperial family of Justinian and his wife Theodora (Ralph-Johannes, 2005).

Science and the colour purple: Aristotle's contribution

For these profits and the exquisite tones of the purple to be enjoyed, it was first necessary for a vast amount of experience and knowledge to be acquired. In the Mediterranean, tradition and technological development came together as long ago as the Late Bronze Age to reach the high degree necessary for taking full use of this important marine resource. But it was especially from the time of classicism and early Hellenism that the use of this dye-matter spread from the south of the Black Sea to the Atlantic Ocean with the setting up of numerous purple workshops. There even arose places where varieties were produced that imitated it, such as the famous Getulian purple of classical authors (Horace, Ep. II, 2, 181; Ovid, Fasti II, 319; Mela, Chorographia, III, 104; Pliny, *NH* VI, 37 and 2002-2005; Silius Italicus). Getulia was a place situated on the coast of Mauritania Tingitana, Mogador (Dedekind, 1898; Herber, 1938; Desjacques and Koeberlé, 1955; Tejera and Chávez, 2004), which became very important in the times of King Juba II (1st century AD).

Greek science furnished meticulous descriptions of the life of the animals that produce the purple liquid and the ways in which they were exploited. The works of Aristotle as a biologist (HA, PA, GA) laid the necessary scientific groundwork that was then built on with subsequent information. In his work, he carefully took into account the observations of his informants, those (including Alexander the Great, his disciple) who brought him animals to examine and his own. Aristotle had conceived two different series of works about life and the environment and its influence on animals – one short, the other long. The short series comprises the treatises On the Parts of Animals and On the Generation of Animals. The long series is much more extensive and includes the definitive editions of his works on biology: Treatise on the Parts of Animals, On the Progression of Animals, On the Soul, On Sense and Sensible Objects, On Memory and Recollection, On Dreams, On Sleep and Waking, On Divination in Sleep, On the Motion of Animals and On the Generation of Animals (330-322 BC). Both series begin with The Parts of Animals (330 BC); he considered it basic (Louis, 1990).

Aristotle's sources as a biologist were authors such as Homer, Hesiod, Hypocrates, Plato, Herodotus (Egypt), Museus, Stesichorus, Simonides of Ceos, Ctesias (India), Aeschylus. But also people with relevant experience: hunters, fishermen (from Assos and Mithylene specially), cattle raisers, fish farmers, bee keepers, butchers and slaughterers. The contact with specialists (doctors, vets), the common sense, the tradition (perhaps the origin of some errors) and his personal experience, do the rest. Following his *Historia Animalium* in ten books (347-342 BC) we can find the information provided by Plutarch (History), Athenaeus (Sophists' Symposium), Aristophanes of Byzantium, and specially Pliny the Elder (Natural History).

Concerning *Historia Animalium*, in spite of the lack of order, which has been pointed out, in this encyclopaedia on animals (including humans), its essential merit lies in the author's having begun with as systematic a classification of animals as he could in the face of the huge task before him. He started off by dividing animals into two major groups: those with blood - *enaima* (corresponding to our vertebrates) and those without blood - *anaima* (invertebrates), which are the ones that interest us here. He then divided the *anaima* into four subgroups: a) molluscs, corresponding only to those now classified as cephalopods, b) malacostraca, comprising most of the higher crustaceans, c) eutoma, which included worms and insects and d) ostracoderms, which included all the animals having a shell such as bivalves, gastropods, echinoderms, etc. Aristotle called these groups "major genera", their divisions he called "genera", and he divided the genera in turn into "species". This classification remained in use until the introduction of the one devised by Carl Linnaeus in the 18th century. One of the most important of his continuators was Pliny the Elder (*Naturalis Historia*) who also described for us the systems used to produce purple dye, but in much greater practical detail (especially IX 125-141). Aristotle began the tradition of writing about the anatomy of the *muricidae* whose habits, ways of life and reproduction, as well as the practical methods employed in catching these marine gastropods for use in purple production, he observed for himself with the fishermen of Lesbos (Louis, 1964). All his findings were subsequently followed by Pliny. The information provided by both of them about the life of these animals on different sea beds and the hard work of extracting the colouring liquid constitute a complex but exciting chapter in the history of purple.

The epigraphic sources

There are numerous literary and epigraphic sources furnishing us with disparate but significant references to purple. Without setting out to provide a systematic account of the subject, they nevertheless introduce extremely useful information on: colour and the society that used this product, the economic features surrounding it, certain aspects of luxury and religion and the criteria employed in valuing certain uses. To the literary information must be added epigraphic information. Apart from the epitaphs on tombstones that speak of the trades carried on by the people who worked with purple in some way (like the most famous *C Pupius C L Amicvs purpurarius,* of the Parma's Museum, CIL XI, 1069a; or even some women like *Beabia Veneria* from Gadir, CIL II, 1743) and some of its manifestations, Antiquity has left us an enormous amount of information on fishing rights contained in Greek epigraphy, from both the classical and the early Hellenistic periods, as well as the Roman period in Greece, which is so often forgotten (Bruneau, 1969; Fernández Nieto, 2003). Important information is also to be found in legal and juridical texts. In 304 the emperor Diocletian ordered a law to be inscribed on marble slabs to be put up in the *fora* of towns and cities in an attempt to check runaway inflation: the so-called Edict on Prices (*Edictum de pretiis et rerum venalium cf.* Mommsen-Blümner, 1893), which contains a great deal of information on purple. Very interesting information provide us too the laws in the various codes of the Lower Empire (the *Codex Iustinianus*, from 534 AD or *Corpus Iuris Civilis*, which includes previous legislation such as the laws drawn up by Gaius and the Theodosian Code).
There is also a short work on the control of production of certain objects of value in the Lower Empire. We know it by the name of *Notitia Dignitatum*, because it refers to the posts of the people responsible for controlling such production. The *Notitia* speaks, among others, about the *procuratores baphiorum*, or those whose job it was to ensure that in the *baphia* (the workshops where purple was produced), the laws and regulations safeguarding certain shades (exclusive to the royal house) were adhered to in the dyeing carried out there. This has enabled us to learn about the distribution of such workshops in the eastern and western parts of the Empire. Papyri are too an important source of information on colour. Among the late papyri of Hellenistic and Roman Egypt there is a wide variety of extraordinary documentation in the form of recipes for making or imitating purple dye. They were studied in the early 20th century by Pfister, who tried to reproduce their formulae. He combined this with an analysis of textiles from the same area containing remains of vegetable and, sometimes, marine dye. I have already spoken about this in mentioning the techniques for analysing colourings.

Archaeological experience in Ibiza (Balearic Islands): purple production workshops

Every subject of research requires a methodology, a way of approaching the subject and understanding the different facets that form a whole. Whatever guidelines it may follow, the system employed for studying any subject, and this one in particular, must adhere to them strictly for the results to be homogeneous. In our case, for the nine years we have been carrying out a research programme, we have based ourselves on a working hypothesis. The text of the *Notitia Dignitatum* (4th century BC), which I have already mentioned, is a compendium of the production of the period, written to enable the governors to control the factories making all things imaginable, including purple. These factories were run by the *Procuratores* or managers. Among the names of the many people in charge of the different types of work it mentions, the text provides information on the *Procuratores baphii.* "Bafiké" in Greek means the art of dyeing and for the Romans, a *baphium* was a place where purple dye was produced. So the *Procuratores* were responsible for ensuring that the making of the dye in these facilities abided by the rules laid down by the State: normal output for trade and strict controls so that the dye known as royal purple, meant, as we have seen, only for the royal family and their close relatives, was not produced. Among the *baphia* in the West the *Notitia* mentions the one in the *Balearic Islands* through the figure of a *Procurator baphii insularum Balearum.*

Purple production on the western Mediterranean was mediated by the Phoenician presence. Ibiza and Formentera had been Phoenician, then Punic, enclaves since the 4th century BC. In other words, they were more closely connected to North Africa and the Phoenician colony of Carthage. Based ourselves on these premises, we put forward the following working hypothesis: the *Baphium of the Balearic Islands* was centred only on Ibiza and Formentera and not Majorca or Minorca, the two largest islands. Ibiza and Formentera are the Pine Islands of the west, with a Phoenician tradition of fish salting and other signs of work with *murex*, which made us think of this possibility. Since the geographical area was small, the research was more focused and it was possible to carry out an exhaustive analysis.

The inspection of the territory and excavation

In such cases, the archaeological research must start with a systematic inspection of the territory based on written sources, references and the presence of certain items. At first we visited and analysed the places where we had information on the presence of *murex* (Alfaro, 2002). In 2001 there were six such sites. At the same time, we began excavating the site at *Pou des Lleó* (*Canal d'en Martí*), the place where we established our working methodology with the malacological elements found there. The structural remains were spectacular. A complex installation that looked like a pitch oven, but turned out not to be one, as there were absolutely no remains of any pitch used for caulking. It consisted of two basins, a circular one, taller and bigger than the other, with the remains of incineration, lime and pebbles. The other, connected to it by a hole, was used to place an amphora in to collect the liquid produced, a sort of bleach used in preparing wool for dyeing. The archaeological materials taken from shell deposits found in Ibiza where very poor but, at the same time, very interesting. We have worked for nine years with important results for the study of the spread of the places at which purple was produced concentrated in a small territory (the island is 45 kilometres long).

We found that production was spread all along the coast of the island (especially on the eastern side, which is nearer the powerful current bringing in the shoals of tuna that were caught at other times of the year) and the beaches of neighbouring Formentera. These were all small workshops in various positions or collecting places with enough animals for us to conclude that they engaged in dye-production rather than simply gathering the molluscs for food, as commonly found at other sites. The workshops are usually situated about six metres above sea level in wind-sheltered areas close to a quiet cove. The dye produced may have been employed for dyeing wool (either in fibre form or already spun) locally prior to its being sold. During the time of the Lower Empire, this process must have been carried out via a *procurator* dependent on the imperial house who may have lived in the town of Ibiza. This was an important port founded by the Phoenicians from which the wool was shipped to its eventual destination. The number of workshops certainly suggests that not all the output was consumed locally (Alfaro and Costa, 2008). The dye-making activity discovered has led us to undertake a new research project focusing this time on local wool production. From a passage by Timaeus we know that Ibizan wool was of good quality. Both the literary and the archaeological evidence is scarce, but the obvious fact that a large amount of purple was produced, coupled with our conviction that the highly valued liquid left the island in the form of dyed wool (Alfaro and Tébar, 2004), has persuaded us of the need to supplement our research in this direction. We intend to work jointly on this with the University of Reims and R. González Villaescusa. After the first exploratory stage, we hope our efforts will yield the desired fruit through analyses of the terrain and the archaeological remains, which are often overlooked.

The spread of purple across the Mediterranean

The use of purple dye is a cultural matter. Its production requires, in the first place, that a colour, which is hard to obtain, expensive and eventually became extremely exclusive, be highly valued by citizens. On the other hand, it is obviously necessary to be in possession of the specific techniques for extracting and handling the dye; techniques that may well have been passed on from generation to generation. But did the exploitation of these purple-producing sites and the setting up of workshops follow the process of Phoenician, Greek and Punic political expansion westwards, or rather, was the collection of these coveted animals just another attraction for the colonisation of some of the islands and coasts of the Iberian Peninsula?

The life of the *muricidae* is dependent on certain specific conditions required for their survival: protection of their reproductive cycle, a habitat with a plentiful food supply and, perhaps, a particular temperature of the water. The ancient biologists and naturalists were very much concerned with the first of these conditions. Aristotle (HA V, 547a 14-16 and 20-21) and Pliny (NH IX, 42) stress the times of the year when they should be collected and when they should not because the animals are breeding. Their advice about these periods (which today we would call the closed season) is linked to the idea that before and after breeding the quality of the dye would not be as good as might be wished.

It is curious that the purple-producing installations on the coasts of Hispania were initially concentrated in areas where there had long been a Phoenician presence. Might the abundance of these molluscs observed on exploratory voyages have been one of the many reasons giving rise to the Phoenician and Punic settlements in these areas? Of course, the phenomenon is also common in the central Mediterranean; Motya might be cited as an example. The hypothesis that the long period of exploitation of the fishing resources of the eastern Mediterranean might have partially exhausted the once rich famous *muricidae* fishing grounds in cities such Tyre, Sidon, Byblos, Sarepta, etc. is tempting, but hard to prove in the current state of research on the phenomenon.

There is a very large amount of work still to be done and few systematic excavations have been planned at the many workshops of which we are aware right across the Mediterranean and in the southern Black Sea region (the north may be too cold in winter for the animals to develop properly).

At all events, the taste for rich cloths dyed with marine purple in bluish and reddish hues lasted throughout the long Byzantium Empire. Silk had already made its way into the area a long time before through the eastern route, but now the inflow of such materials was much greater. The luxury of the courts of emperors such as Constantine, Justinian and Theodosius, or of the emperors and empresses who referred to themselves as "born of the purple", makes it quite clear that economic activity to do with purple production was a symbol of imperial power adopted also by the upper classes of a complex society, especially that located in the eastern Mediterranean.

Bibliography

Alfaro C. (1984). *Tejido y cestería en la península Ibérica. Historia de su técnica e industrias desde la prehistoria hasta la Romanización*, Biblioteca Prehistorica Hispana, XXI, Madrid.

Alfaro C. (2002). "Ebussus y la producción de púrpura en el Imperio romano", in M. Khanoussi, P. Ruggeri and C. Vismara (Eds.), *Atti del XIV Convegno di Studio sull l'Africa Romana*, Roma, pp. 681-696.

Alfaro C. and Tébar E. (2004). "Aspectos históricos, económicos y técnicos de la producción de púrpura en la Ibiza romana", in C. Alfaro, J.P. Wild and B. Costa, *Purpureae Vestes. Textiles y Tintes del Mediterráneo en época romana*, Valencia, pp. 195-210.

Alfaro C. (2005). "Gold Textiles from a Roman Burial at Munigua (Mulva, Seville)", *NESAT* VII, Oxford, pp. 1-4.

Alfaro C. and Costa B. (2008). "New contributions to the study of purple dye production in Ibiza: the finds of Cala Olivera", in C. Alfaro and L. Karali (Eds.) *Vestidos, textiles y tintes. Estudios sobre la producción de bienes de consume en la Antigüedad. Purpureae Vestes* II, Valencia, pp. 195-208.

Andronikos M. (1977). "The Royal Graves at Vergina", *Athens Annals of Archaeology* 10, pp. 40-72.

Augier H. (1985). "Utilisation des végétaux marins à travers les ages: vision historique, contemporaine et prospective", in *Exploitation de la mer de l'Antiquité à nos jours, I La mer, lieu de production*, Vèmes Rencontres internationales d'Archéologie et d'Histoire. Antibes, octobre 1984, Juan-les-Pins, pp. 11-43.

BAKER J.T. (1974). "Tyrian Purple: an ancient dye, a modern problem", *Endeavour*, vol. XXXIII, nº 118, pp. 1-17.

BESNIER M. (1910). Daremberg and Saglio, *Dictionnaire des Antiquités Grecques et Romaines* Vol. IV.1, pp. 769-778, *s.v. Purpura*.

BORGARD P., BRUN J.-P. AND PICON M. (Eds.) (2005). *L'Alun de Mediterranée, Actes du Colloque International, Naples 2003*, Collection du Centre Jean Bérard, 23, Naples, Aix-en-Provence, 2005.

BRUNEAU P. (1969). "Documents sur l'industrie délienne de la pourpre", *Bulletin de Correspondence Hellènique* 93, 759-791.

BRUNELLO F. (1973). *The Art of Dyeing in the History of Mankind*, Vicenza.

CARDON D. (2003). *Le monde des teintures naturelles*, Paris; (2007), *Natural Dyes. Sources, Tradition, Technology and Science*, London.

CARDON D. (2007). *Natural Dyes. Sources, Tradition, Technology and Science*, London.

CARILE A. (2000). "Produzione e usi della porpora nell'impero bizantino", in A. Carile (Ed.), *Imagine e realtà nel mondo bizantino*, Bolonia.

COLONNA F. (1616). *Opusculum de Purpura*, Roma.

D'ARCY THOMSON W. (1947). *A Glossary of Greek Fishes*, London.

DAVID D. AND HERBER J. (1938). "La pourpre de Gétulie", *Hesperis* XXV, 97-99.

DEDEKIND A. (1898). "Sur la fausse pourpre des anciens", *Archives de Zoologie Experimental* VI, pp. 70-78.

FERNÁNDEZ NIETO F.J. (2003). "Titularidad y cesión de los derechos de la pesca marítima en la antigua Grecia", *Symposion*. Vorträge zur griechischen und gellenistischen Rechtsgeschichte, Wien 2006, pp. 207-232.

FOL W. (1877). Daremberg et Saglio, *Dictionnaire des Antiquitées Grecques et Romaines*, Vol I, 2, pp. 1325-1331, *s.v.* Color.

KELLER O. (1913). *Die antike Tierwelt,* Vol. II: *Vögel, Reptilien, Fische, Insekten, Spinentiere, Tausendfüssler, Krebstiere, Würmer, Weichtiere, Stachelhäuter, Schlauchtiere*, Leipzig.

LACAZE-DUTHIERS H. (1859). "Mémoire sur la pourpre*", Annales des Sciences Naturales,* 4e Série, Zoologie, XII, pp. 5-84.

LINDNER G. (1989). *Guide des coquillages marins. Descriptions, repartition systématique*, Neuchâtel-Paris 1989.

LOUIS P. (1964). *Aristote. Histoire des Animaux,* Budé Paris, Introduction.

MARINATOS N. (1984). *Art and Religion in Thera. Reconstructing a Bronce Age Society,* Athens.

MOMMSEN T. AND BLÜMNER H. (1893). "*Der Maximaltarif des Diokletian*", Berlin.

MORETTI L. (1977). In AA.VV., *Storia e civiltà dei Greci.* 8. *La società ellenistica*, Milan.

NAEGEL L.C.A. AND COOKSEY C.J. (2002). "Tyrian Purple from Marine Muricids, specially from Plicopurpura pansa (Gould, 1853)", *Journal of Shellfish Research* 21: 193-200.

NAEGEL L.C.A. (2005). "The effect of periodically "milking" to obtain Tyrian purple from *Plicopurpura pansa* (Gould, 1853) on the frequency of expulsion and mortality", *Journal of Shellfish Research* 24: 85-90.

RALPH-JOHANNES L. (2005). *Bisanzio la seconda Roma*, Newton & Compton editori, 2005 Roma.

REINHOLD M. (1970). *History of Purple as a status symbol in Antiquity,* Col. Latomus 116, Brussels.

SPANTIDAKI J. AND MOULHERAT C. (in print). "Vestiges de textiles pourprés découverts en Grèce antique", in *Purpureae Vestes III*, Valencia-Napoli.

TÉBAR E. AND WILSON A. (2008). "Classical and Hellenistic textile production at Euesperides (Benghazi, Lybia): preliminary results", in C. Alfaro and L. Karali (Eds.) *Vestidos, textiles y tintes. Estudios sobre la producción de nienes de consume en la Antigüedad, Purpureae Vestes* II, Valencia, pp. 49-59.

TEJERA A. AND CHÁVEZ E. (2004). "La púrpura getúlica de la Mauritania Tingitana", in C. Alfaro, J.P. Wild, B. Costa (Eds.), *Purpureae Vestes* I. *Textiles y tintes del Mediterráneo en época romana*, *Purpureae Vestes* I, Valencia, pp. 237-240.

TREADGOLD W (1997). *A History of the Byzantine State and Society*, Stanford.

UNDERWATER ARCHAEOLOGY, MARINE ECOLOGICAL HISTORY AND MARINE ENVIRONMENTAL HISTORY

HOW CAN UNDERWATER ARCHAEOLOGY, MARINE ECOLOGICAL HISTORY AND MARINE ENVIRONMENT HISTORY WORK TOGETHER?

Francesco Tiboni
AIASub - Italian Society of Underwater Archaeologists
e-mail: francesco.tiboni@alice.it

Key-words: *underwater archaeology, geophysics and archaeology, wrecks, fish bones*

Introduction: what is Underwater Archaeology?

Underwater archaeology studies many aspects of ancient life linked to the sea and water, based on material remains left by ancient civilizations. However, since underwater archaeology has often been linked with wrecks and treasures recovery, the subject is usually interpreted as the study of ancient ships and navigation. Thus the scope of underwater archaeology was reduced to sole *naval archaeology* or *sea-trade history*.

The mile stone in underwater archeology, especially of wrecks and their diffusion in the Mediterranean, was the find in the late 1960s of the Ulu Burun wreck (Kas – Turkey), dated to the XIV century BC (Bass, 1986; 1989; Pulak, 1966; 1988). The information provided by the excavation of the wreck and its load allowed archaeologists and historians to understand how men and goods moved since the pre- and proto-historical times through the Mediterranean and permitted to elaborate the first hypothesis about sea trade and cultural contacts of that time. This discovery increased archaeological attention for underwater sites and demonstrated that shipwrecks must not be read as a sort of "snapshot" of a sunken object, but as a way to better understand relationships among different cultures and to have a more precise idea of human culture evolution. Starting from this first experience, sea has been read not only as a part of the human landscape, but as an important element to be studied and analyzed by itself.

Indeed, starting from the Ulu Burun wreck, many other wrecks (Dell'Amico, 2005), coastal sites and structures have been studied by historians and archaeologists. The various finds that, among others, include wooden elements and structures, leather or organic fibres used to create ancient fabrics, could afford important information about ancient technologies, cultural changes and social structure of a settlement as well as of a whole culture (Bradley, 1990; Steffy, 1994; Dean, 2009). Moreover, the birth of the so called "maritime archaeology" has been producing a more detailed description of the evolution of the sea area during times and helped archaeologists to study better the relationships during the centuries between man and sea (Janni, 1996).

It should be noted that George Bass, the first global pioneer in underwater archaeology, tried to put in evidence that underwater archaeology represents just a branch of archaeology, a sort of technical variation. In other words, underwater archaeology was created and developed parallel to *field archaeology*, since the only difference between *in-land* and *underwater archaeology* is the environmental conditions in which archaeologists work. Indeed, Bass (1966) wrote that "the archaeologist has adapted himself to every kind of environment offered on our planet's surface, but none is so alien as that which he meets beneath the surface of its waters".
Since the publication in 1966 of this first manual, technological techniques have been renovated and improved due to adoption of technologies and research methods, originally developed for industry, biology, geology and oceanography (Dean, 2009). Thanks to these new methods and practices, underwater archaeology has now become a multidisciplinary science and every archaeological exploration can be considered as the result of a wide range of different sciences. This is why, starting at least from the last ten years of the 20^{th} century, underwater archaeologists have started working in collaboration with historians, biologists and geologists, creating a close mutual relationship, often useful to give a correct interpretation of historical events on the one hand and, on the other, to have a more precise idea of marine environmental evolution, on the base of fish species distribution, ecological or geological changes of the seashore.
The paper, accordingly, examines the multidisciplinary fields, concerned with underwater archaeology research, the interdisciplinary collaboration between them and the problems involved.

Underwater Archaeology and Marine Environment

We start with examination of the reciprocal relationships between underwater archaeology and marine biology.
From an archaeological point of view, a site placed beneath water surface preserves well many finds, mainly if they happened to be covered with sand shortly after their submersion. In underwater environment, in fact, sand or mould cover protects them against waves' erosion, especially in shallow water, against chemical decay and various marine animals, nourishing on organic materials. Seabed cover along with the scarcity of oxygen and the fact that the oxidation and decomposition processes are very slow provide preservation of various types of remains, quite often than not, much better than on land site. Particularly, organic finds are better preserved in anaerobic environment (as shown in Figure 1); thus, a thorough knowledge of underwater environment could help archaeologists to understand how a site is created, how it develops and to explain why some elements of an underwater site, for instance the wooden parts of an ancient sunken ship (shipwreck), could be found during digging, and why some other appear damaged or are not preserved (Palma, 2005).
Indeed, in recent years, many studies have been held on submerged archaeological sites to explain the effects that natural marine environment could have on underwater finds and human products, particularly facing two opposite aspects: the problems of microorganism effect on organic elements such as wood, clay, leather, on animals or fish bones,

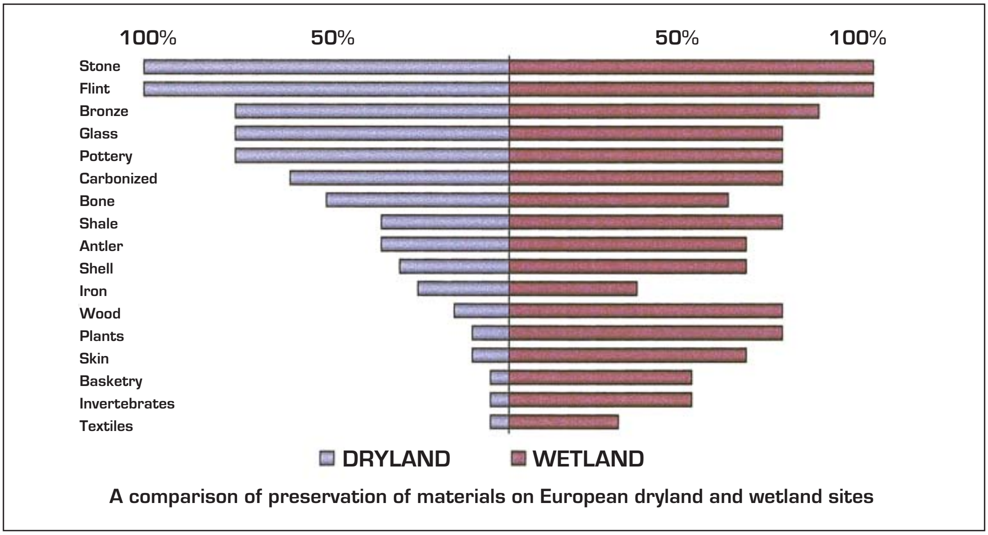


Figure 1. Preservation of materials (After Bowens 2009, p. 17).

as well as on inorganic material, like metal (Murphy, 1990; Martin, 1995; Redknap, 1997; Palma, 2005).

In sites that harbour shipwrecks or buildings structures, such as pile-dwellings, or various types of sea walls (breakwaters, piers and quays), the presence of microorganisms like shipworm (*Teredo navalis*) algae or fungi is very common, especially in temperate waters. These microorganisms cause to a slow and progressive destruction of all the exposed elements. An x-ray picture of an ancient wooden element rescued from a submerged wreck provides a precise idea of how these microorganisms destroy wood by creating tunnels in it (Figure 2).

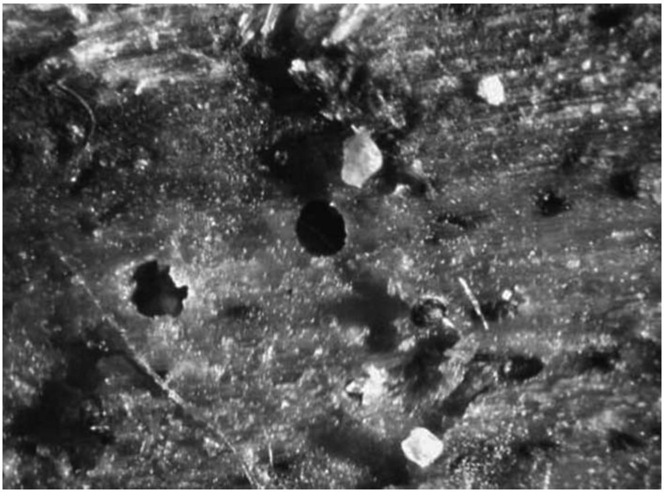


Figure 2. Microscope image of the effect of Teredo navalis (After Palma, 2005 p. 327).

Furthermore, considering wooden wrecks, one can easily understand how the effects of a progressive erosion of exposed organic coincide to in site creation, transforming a complete ship in a sort of wooden skeleton (Figure 3).

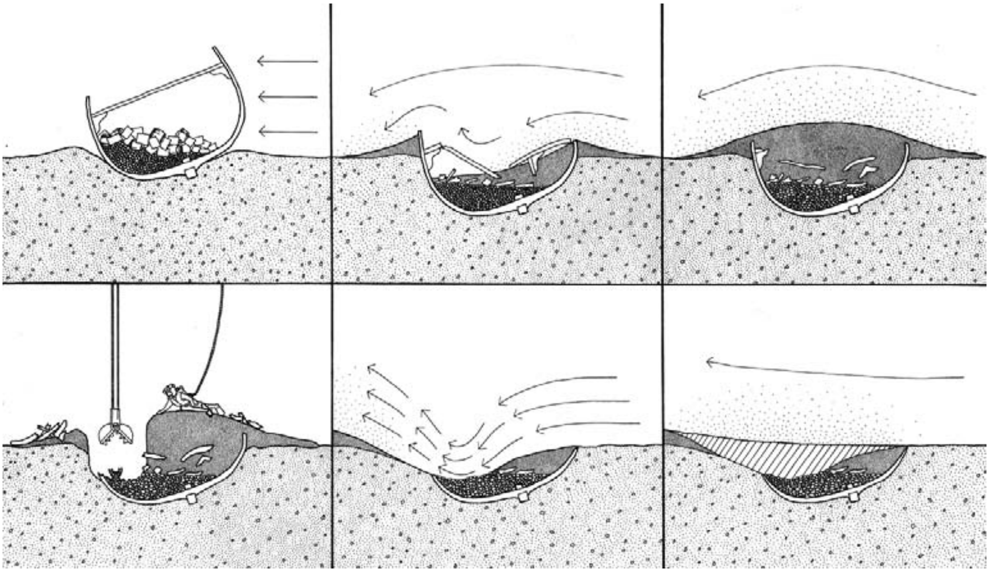


Figure 3. Wreck creation. After Bowens 2009, p. 29 (drawing by Graham Scott).

In other words, a precise analysis of every single find could help biologists to explain how microorganism act on different materials, allowing the archaeologists as well to have a full comprehension of the dynamics involved in the creation of an underwater site (Murphy, 1990; Redknap, 1997).
The "opposite" aspect is the effect of the presence of human products like wrecks, amphorae or submerged structures have during time on local biosphere (Parker, 1981; MacLeod, 1995). For instance, in a shipwreck site, exposed amphorae are often linked with the presence of fauna and algae, as these pottery containers are often used by some species, like octopuses or morays, as burrows (Figure 4).
Even modern metal wrecks, such as those ships that sunk during the two World Wars in the Mediterranean area, have been transformed during time into local submerged islands, strongly inhabited by fishes, corals and algae (Figure 5).
In some cases, the presence of these microorganisms concur in a complete site transformation: surveys conducted in recent years in southern Italy have demonstrated that in the Crotone area, wreck loads have been transformed by sea into submerged reefs, often difficult to be recognized.
Thus, site preservation is not the sole purpose of a close collaboration between the two sciences; the analysis of local ecology and its biologic components is, in fact, nowadays often used to determine the age of a site. This is done on the base of algae presence and

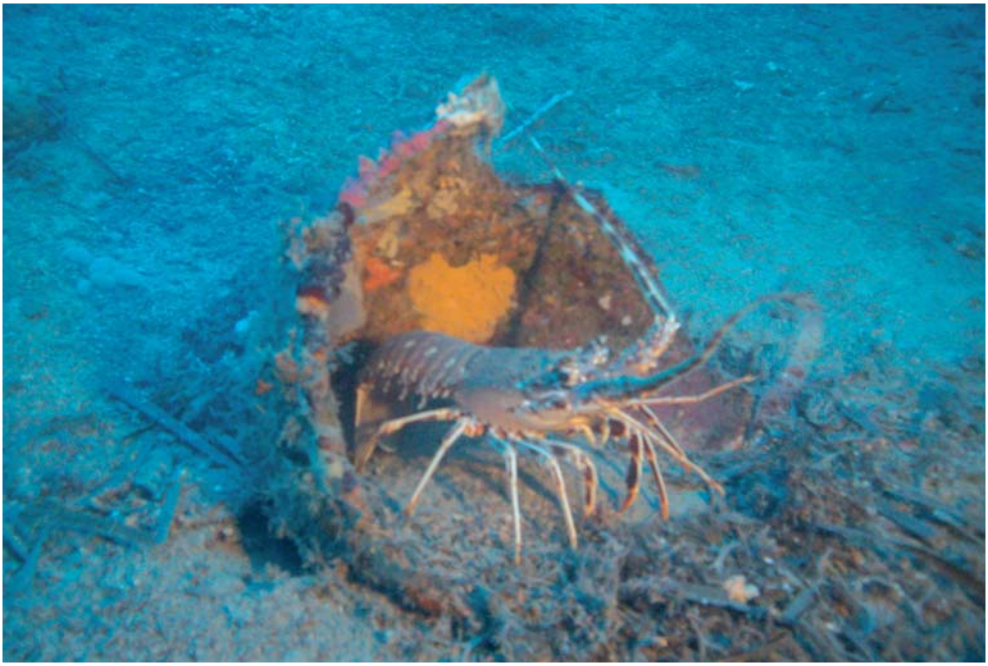


Figure 4. A lobster in a Roman pottery (photo by F. Tiboni).

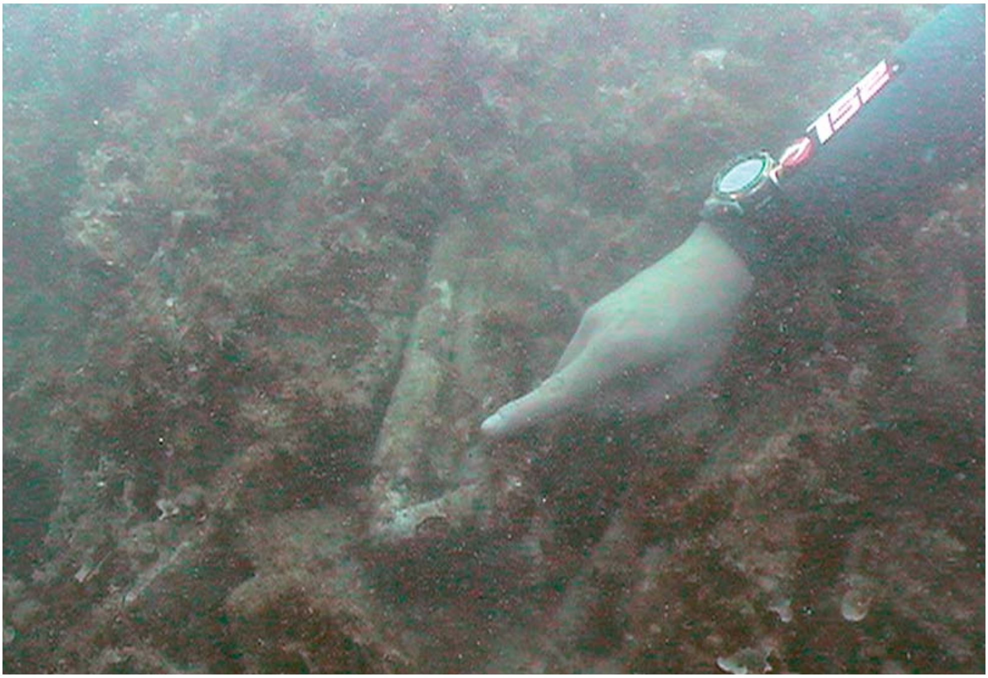


Figure 5. A roman amphora now part of an artificial reef (photo by F. Tiboni).

growth, or with diatom analysis (Battarbee, 1988), to evaluate deposit conditions as well as to create a correct plan of finds maintenance on site (Davidde, 2002), as strongly recommended by the recent UNESCO convention on underwater cultural heritage and archaeological finds.

Marine Archaeology and History

Many scholars argue (Janni, 1996) that the use of historic texts, especially of those about ancient fisheries or sea trade, has to be considered a sort of a baseline for the study of the so called *seascape* in ancient times, at least since the Greek or Roman era. The increase in maritime and underwater archaeological activities since the second half of the twentieth century has, however, provided a lot of new archaeological evidences to challenge this traditional view.

Recent evolution of maritime archaeological sciences, linked to the use of geophysical instruments and techniques, has demonstrated that the study of the human signs found underwater allow us to confront and change the understanding of many of the convictions created by texts, as well as contemplating the missing information. For instance, the minimizing by the documents of the role of non-Roman sailors, Punic, Etruscan or Greek in the Roman Empire. Especially the role of the Etruscans was ignored by the Roman historians, while the Etruscan wrecks found near Tuscany or Southern French coasts point to the importance of Etruscan in Tyrrhenian navigation.

In light of such a contradiction between the historic documents and the archaeological evidence, one should ask why? The explanation should be looked for in the character of the documents and the Roman mentality. For instance, the need of the Roman Empire to celebrate its power and to evocate mythical origin didn’t allow official historians to draw a precise picture of the real strength of other actors, such as above-mentioned, involved in maritime activity. Since the Roman Empire was centralistic, the Roman historians had to follow the Imperial throne's policy, among others, regarding describing the various maritime enterprises inside the *Mare Nostrum*. In other words, these texts cannot be considered as a sole and credible source to understand *seascape evolution*, and archaeological evidence has to be taken into consideration in order to get a fuller and more authentic picture.

On the other hand, a combined study held by historians with the analysis of direct evidence contributed by archaeology, permits archaeologists and historians to have a more precise idea of how ancient Greeks or Romans used to exploit sea and fishes (Rieth, 1998). The study of pottery containers to transport *garum*, salted fishes and wine, along with historical sources, has recently (Peacock, 1986; Caravale, 1997) provided information about the presence and the diffusions of marine species, their use as nourishments and their economic impact in ancient civilizations. These studies point to the importance of non-Roman production and trade and also shed light on the role of pre- Roman shipbuilding or trading traditions.

Furthermore, excavations of fisheries in coastal settlements have furnished important elements to understand how and when fishes were bred, where they were sold and eaten and who was involved in these activities (Trakadas, 2003).

The presence in some wreck-sites of fishing-nets, often testified by little lead weights or metal rings, of fish-hooks of metal harpoons, allows us to argue that many of the sunken ships found around Mediterranean coasts used to fish during their travel (Dell'Amico, 2005). Some, as has been suggested, for instance, by the wooden box found on the Fiumicino boat wreck (Boetto, 1999; 2000; 2007), were of a specific economic and trade use. The wooden box was interpreted as a sort of "*aquarium*", a container for transporting fresh fishes from the sea to the local markets. Unfortunately, no remains of fish bones were found on those sites; the identification of fish species, fished by the various vessels on their way, or of fishes that were transferred to and traded in local market has to be derived from written documents and artistic evidence, such as mosaics, drawings or paintings.

MULTIDISCIPLINARY RESEARCH REGARDING PRE-HISTORY

Collaboration between archaeology and marine sciences, such ecology, biology and archaeometry or geology, are very fertile for pre-historical studies, mainly due to the lack of written sources; in such cases the field study of ancient environmental conditions provides the main clue for a correct interpretation of human marine activities. In pre-historical studies every archaeological find can be studied not just by itself, but as a part of a complex environment, natural or human, and can be used to identify the effect of human actions as well as of natural forces on a particular site in a particulate moment (Boyce *et al.*, 2004; Dean, 2006).
The following examples will illustrate the collaboration between pre-historical archaeology and marine sciences. The first case study concerns the coastal caves of the Cagliari area, particularly in those Neolithic sites near the so called "*Sella del Diavolo*". Archaeologists found in those caves fish-bones in archaeological contexts that point to fishing of big animals, such as dolphins or tunas, and to shells' of the *Cardium edulis* type, collected by men of the Stone Age. Like the fish, these bivalves were part of the cave people diet (Atzeni, 2003). A combined study of some particular finds of these sites provided the archaeologists with important information about the inhabitants of the ancient Sardinian caves: about their way of living, their nourishments by marine animals as well as the social structure of the human groups, putting in evidence the presence of specialized fishermen, who used shells and fish-bones as ornaments to celebrate their captures both with emphasizing their special social/economic status (Orsoni, 1880; Atzeni, 1962).
It should be indicated that during Neolithic era the use of shellfishes was common not only for nourishment and pearl-necklaces but for the decoration of a particular pottery class, *ceramica cardiale*, as well. This type of pottery was mainly diffused in Northern Mediterranean area during the 6th millennium BC (Atzeni, 1981).
To sum up, the study of these caves lead archaeologists to understand that this area of Sardinian coasts had been inhabited by "hunters-gatherers", engrossed in sea exploitation as well, and that fishers could have played a pre-eminent role inside the society of that time.

Another case study concerns pre-historical pile dwelling sites studied in the alpine region, in northern Italy. The study of ancient shells, insects or pollens, carried out by biologists, permitted archaeologists to understand environmental conditions of the sites, and enabled them to achieve information about nourishment and health of ancient inhabitants. The biological research also helped archaeologists to give a precise interpretation of many of those particular wooden structures of the settlements that cannot be treated as structural elements of villages but as, for instance, fish traps (Girod, 2002).
Furthermore, a correct analysis of evidence connected to aquatic environment under the wooden dwellings allowed archaeologists to argue that many of these pre-historical settlements were built inshore, in the deep part of lakes or rivers. Thus, thanks to these new scientific studies, archaeologists could now definitely surpass the original theory of pile-dwelling sites as coastal buildings, created by ancient people only on the shores (Magny, 1984; Schlichterle, 1995; Pedrotti *et al.*, 2004).
Another combined study of a Mesolithic site recently found in Venice Lagoon, near the so called "*Isola delle Statue*", between Marghera and Venice, allowed us to give a firm proof of the presence of a little group of Mesolithic hunters and gatherers (Tiboni, 2010). In this case, the analysis of the soil structure, with the presence of flint tools in stratigraphy in association with some carbons under a layer of sands with shells of *Cardium edulis* in it, allowed us to identify the site as a little station, possibly used during a brief period. It was located on the shore of an ancient river, dated to the last part of the 8^{th} millennium BC and submerged before the end of the 4^{th} millennium BC by the entrance of salted water from the sea to the inner part of the Lagoon.
The collaboration between us, archaeologists, geologists and marine biologists has demonstrated that this site could be considered one of the first evidences of human presence in the territory of Venice and helped us to give a valuable interpretation of the environment evolution during the Stone Age.

Ending notes

Up till now we have emphasized the important role of particularly marine biology to underwater archaeologists in site interpretation. Nevertheless, since recently, the awareness to archaeology's role to provide biologists with important information on seascapes and sea exploitation through different periods has significantly been increased. The collaboration between archaeology and biology has produced a new field of research, called *zoo-archaeology* or *forensic archaeology* (Blau Ubelaker, 2009). The interdisciplinary study, linked with the study of ancient bones and organic rests, has increased the possibility to obtain data about ancient nourishments and biological evolution of men and environment. Unfortunately, even if studied in many of the European universities, *forensic archaeology* is not yet very common in Italy, where archaeology is still more considered a branch of "art history" than an independent discipline.

Bibliography

Arnauld P. (1998). "La navigation hauteriere en Mediterranee ancienne d'apres les donnees des geiographes anciens: quelques examples" in Rieth E. (Ed.) *Mediterranee Antique: pêche, navigation, commerce*, 75-87.

Atzeni E. (1962). "The Cave of San Bartolomeo, Sardinia", *Antiquity* XXXVI: 84-189.

Atzeni E. (1981). "Aspetti e sviluppi culturali del neolitico e della prima età dei metalli in Sardegna" *Ichnussa*. Milano, pp. 32-36.

Atzeni E. (2003). *Cagliari Preistorica*, Cagliari.

Bass G. (1966). *Underwater Archaeology*, London.

Bass G. (1986). "A Bronze Age shipwreck at Ulu Burun (Kas): 1984 Campaign", *American Journal of Archaeology* 90: 269-296.

Bass G., Pulak C., Collon D., and Weinstein J. (1989). "The Bronze Age shipwreck at Ulu Burun: 1986 Campaign", *American Journal of Archaeology* 93: 1-29.

Blau S. and Ubelaker D.H. (2009). Handbook of Forensic Archaeology and Anthropology, *World Archaeological Congress Research Handbooks.*

Boetto G. (1999). "Le navi di Fiumicino: un contributo alla ricostruzione della topografia del porto di Claudio e della geomorfologia costiera", *Meded* 58, 41.

Boetto G. (2000). "New Technological and Historical Observations on the Fiumicino I Wreck from Portus Claudius (Fiumicino, Rome)", *Down the River into the Sea. Proceedings of the VIII International Symposium on Boat and Ship Archaeology, Gdansk 1997 (J. Litwin Ed.)*, 99-102, Gdansk.

Boetto G. (2007). "Fishing vessels in antiquity: the archaeological evidence from Ostia (Rome)", *Net and fishing gears in classical antiquity*, Cadiz.

Bowens A. (Ed.) (2009). "Underwater Archaeology. The NAS guide to principles and practice", London.

Bradley R. (1990). *The Passage of Arms: an archaeological analysis of Prehistoric Hoards and Votive Deposits*, Cambridge.

Battarbee R.W. (1988). "The use of diatom analysis in archaeology: a review", *Journal of Archaeological Science* 15: 621-44.

Caravale A. and Toffoletti I. (1998). *Anfore antiche,* Rome.

Davidde B. (2002). "Underwater archaeological parks: a new perspective and a challenge for conservation – the Italian panorama", *The International Journal of Nautical Archaeology* 31.1: 83-8.

Boyce J.L., Reinhardt E.G., Raban A. and Pozza M.R. (2004). "Marine Magnetic survey of a submerged Roman Harbour, Cesarea Marittima", *The International Journal of Nautical Archaeology* 33.1: 122-36.

Dell'Amico P. (2000). "Le origini antiche e lo sviluppo della nave", *Rivista Marittima – Supplemento giugno 2000*, Rome.

Dean M. (2006). "Echoes of the past: geophysical surveys in Scottish water and beyond", in Jones R.E. and Sharpe L. (Eds.), *Going over old ground – Perspective on archaeological geophysical and geochemical survey in Scotland*, 80-7. BAR, British Series 416, Oxford.

Dell'Amico P. (2005). *Relitti del Mediterraneo*, La Spezia.

Girod A. (2002). "I molluschi acquatici e terrestri del Bronzo Antico e del Bronzo Medio al Lavagnone (BS). Un approccio Metdologico", *Notizie Archeologiche Bergomensi* 10: 65-84.

Janni P. (1996). *Il mare degli antichi*, Bari.

MacLeod I.D. (1995). "In Situ corrosion studies on the Duart Point Wreck", *The International Journal of Nautical Archaeology* 24.1: 53-9.

Martin C.J.M. (1995). "Assessment, stabilisation and management of an environmentally threatened seventennth-century shipwreck off Duart Ponit, Mull" in A. Berry and I. Brown (Eds.) *Managing Ancient Monuments: an Integrated Approach*, 181-9. Clyweland.

Murphy L.E. (1990). "8SL17: Natural Site Formation Process of a Multiple-Component Underwater Site in Florida", *Submerged Resources Center Professional Report No. 12*, National Park Service, Santa Fe, New Mexico.

Palma P. (2005). "Monitoring of shipwreck sites", *The International Journal of Nautical Archaeology* 34.2: 323-331.

Parker A.J. (1981). "Stratification and contamination in ancient Mediterranean Shipwrecks", *The International Journal of Nautical Archaeology* 10.4: 309-35.

Pulak C. (1988). "The Bronze Age shipwreck at Ulu Burun: 1985 Campaign", *American Journal of Archaeology* 92: 1-37.

Pulak C. (1996). "Dendrochronological Dating of the Uluburun Shipwreck", *The Institute of Nautica Archaeology Quarterly* 23:1: 12-13.

Magny M. (1984). "Les palafittes aujourd'hui: bilan et perspective, un siècle d'archéologie lacustre", *Revue Archéologique de l'Est* 35, I-II: 41-61.

Orsoni F. (1880). "Recherches préhistorique dans les environs de Cagliari" in *Materiaux pour l'Histoire primitive et naturelle de l'homme*, XVI année XI, 57.

Peacock D.P.S. and Williams D.F. (1986). "Amphorae and the Roman economy: an introductory guide", London.

Pedrotti A., Felber M. and Della Torre U. (2004). "Le palafitte dell'arco alpino meridionale", in *Auf den Spuren der Pfahlbauer*, pp. 66-71, Bern.

Redknap M. (Ed.) (1997). *Artefacts from wrecks: Dated Assemblages from the Late Middle Ages to the Industrial Revolution*, Oxford.

Rieth E. (Ed.), 1998. *Mediterranee Antique: pêche, navigation, commerce*, Paris.

Schlichterle H. (1995). "Neue Fundstellen im Federseemoor bei Bad Buchau, Oggelshausen, Alleshausen und Seekirch, Kreis Bibearch", in *Archaologische Ausgrabungen in Baden-Wurttemberg*, pp. 57-62, Baden.

Spence C. (Ed.) (1994). *Archaeological Site Manual*, London.

Steffy J.R. (1994). *Wooden ship building and the interpretation of shipwrecks*, London.

Tiboni F. (2010) (forthcoming). "Le selci di isola delle Statue", in *Atti del III convegno Nazionale dell'AIASUB – Manfredonia 2007*, EdiPuglia.

Trakadas A. (2003). "The Archaeological evidence for Fish Provessing in the Western Mediterranean" in *Ancient Fishing and Fish Processing in the Black Sea Region*, Denmark, pp. 47-82.

WHAT USE ARE OLD FISH BONES IN HELPING TO UNDERSTAND THE HISTORY OF MARINE ANIMAL POPULATIONS?

Matthew J. Collins[1], Jennifer Harland[1], Oliver Craig[1], Kristine Korzow Richter[2], Nienke van Doorn[2], Clive Trueman[3]
e-mail: mc80@york.ac.uk

Key-words: *ZooMS, collagen, mass spectrometry, identification, peptide mass fingerprint*

Abstract

Fish remains have a rich presence in the archaeological and paleontological record, as bones, teeth, scales and otoliths. Until fairly recently most research has focused upon the identification of these remains using morphological characteristics, with identification often being very difficult. In some instances up to 95% of fish bones are not diagnostic and, because fish bones readily fragment, the resulting particles lack the characteristic morphology required to identify them to species. However in the past decade there has been increased interest in molecular analyses. DNA has been used to discriminate between fish species, and populations, but DNA itself is not a major component of the archaeological fragments. With the exception of otoliths, fish remains are a composite of tiny mineral crystallites (apatite) and a fibrous protein (collagen). The mineral crystallites undergo rapid diagenetic change, but in fresh material inorganic isotopes can track changes in water masses. The protein collagen is slowly decomposed, but whilst still present (which can be for more than 500000 years), isotopic composition can be used to assess the tropic level of the fish, and potentially track changes in the ecosystem structure. Using protein mass spectrometry it is possible to fingerprint the collagen sample novel method we term ZooMS (Zooarchaeology by Mass Spectrometry), in which collagen is isolated, fragmented enzymatically and the pattern of fragments characterised using soft-ionization mass spectrometry. ZooMS can be used for the identification of archaeological fish bones and scales. This method is also applicable to worked bone, particularly relevant because craftsmanship often destroys vital clues to species identity.

1 BioArCh, Department of Archaeology, Biology and Chemistry, York (United Kingdom).
2 Department of Biology, The Pennsylvania State University, University Park, Pennsylvania (United States of America).
3 University of Southampton Waterfront Campus, European Way, Southampton (United Kingdom).

INTRODUCTION: FISH BONES, FISH BONES

The archaeology of marine ecosystems has been the subject of much recent research in both academia and the popular press (e.g., Roberts, 2007; Rick and Erlandson, 2008). Archaeological fish assemblages comprise primarily accumulations of bones, with some teeth, scales and otoliths. These assemblages can provide insight into fishing strategies (Barrett *et al*., 1999), economic and trade patterns (Barrett *et al*., 2008) diet, resource availability, social relationships (O'Day *et al*., 2002) species ranges, diversity, and mobility (Speller *et al*., 2005), and past climate change (Enghoff *et al*., 2007). The range of applications reflects both the importance of fish to past economies, and the diverse range of species and ecologies that can be studied. However despite the potential of fish to illuminate the history of the marine populations as much as of 95% of all archaeological fish bones are not diagnostic, while many remains survive as fragments that are so small that they lack the characteristic morphology required to identify them to species.
This mini review sets out to illustrate the potential information that can be obtained from fish bones for historical and archaeological studies of marine exploitation.

Archaeological fish

Archaeological fish remains have traditionally been identified using morphological analysis, based on comparisons with reference collections. Fish bones, otoliths (the calcium carbonate fish "ear bones"), teeth and scales can all be identified to varying degrees of taxonomic precision, but differential survival can mean that bones sometimes survive when otoliths do not, and vice versa. Until the last few decades, few archaeological excavations had adequate, rigorous sampling strategies in place for the recovery of fish remains (Wheeler and Jones, 1989). Good recovery requires wet sieving to at least 1 mm, but if fish remains are only collected by hand during excavation, then only the larger elements from the larger fish will be identified – a bias present in some older published accounts of fish remains. However, with the advent of routine sieving of archaeological deposits, large numbers of tiny bone fragments are frequently recovered. Many of these are from fish remains, yet they can be so highly fragmented that identification is impossible for the majority of the assemblage. That said, the minority of fragments that *can* be identified are often very informative.
Traditional zooarchaeological investigation relies on good access to comparative reference collections and personal expertise, and it can produce reports detailing information about the *taxa* exploited, their sizes, likely fishing methods, seasonality, temporal changes, etc. The sizes of fish found can be determined by broad comparison with modern specimens, or by detailed metrical analysis, and can provide information about the habitats being exploited and precise season of capture. Butchery marks and differential representation of elements can provide information about fish preservation, trade and exchange, sometimes across great distances. Temporal changes in *taxa* and sizes exploited can lead to conclusions about changing fishing methods, changing environmental conditions, and over-exploitation of resources.

Bone composition

Fish bone (and scale) is composed of two major components, bone mineral and collagen (Figure 1). The dominant organic component of bone is Type I collagen. This is a fibrous

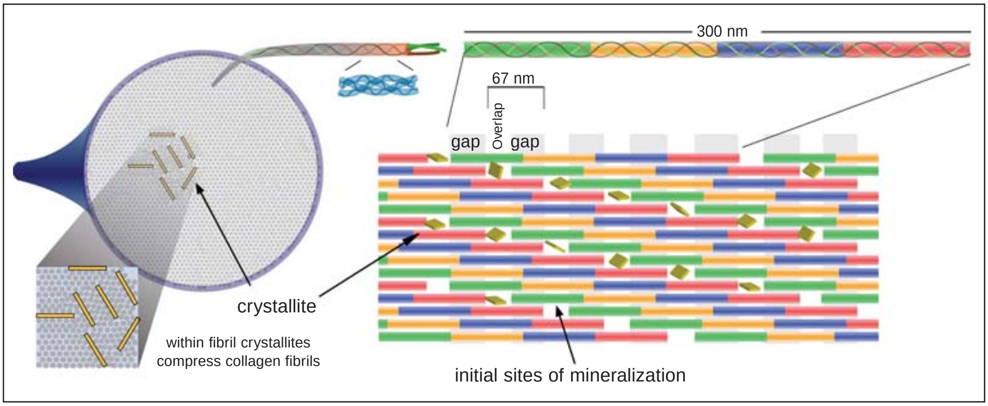


Figure 1. Schematic organization of collagen. Collagen is composed of a triple helix arranged in a quarter stagger, leading to gaps, wherein which apatite is believed to initially precipitate. Minerals also grow within the fibrils (Burger et al., 2008) resulting in compression of the individual triple helices.

protein formed of three chains each of slightly more than 1000 amino acids, wound together as a triple helix into a strand 300 nm long, which self assembles into microfibrils offset by approximately 67 nm (Figure 1). The offset means that there has to be a gap between the molecules (67/300 = 4.8) therefore for every 67 nm repeat, part has five molecules in cross-section (the overlap region) whilst another part has only four (the gap region). These staggered fibrils form into bundles of hundreds to a few thousand triple helices in cross-section and of great length. As the bone mineralises, it gradually becomes filled with mineral which both occupies the free volume between fibrils and within the gap regions but also compresses the fibril itself due to the growth within the overlap regions distorting the fibril (Burger *et al*., 2008).
There has been increasing interest in the application of molecular based records from the hard tissues of fish, and these have been used for identification and to understand migration, ecology. Many of these methods have been applied to both modern fish and ancient fish populations.

Isotopic investigations

Analysis of the light stable isotopes in fish bone collagen can reveal the animal's main dietary protein sources whilst the tissue was forming. This technique offers the possibility of bypassing some of the uncertainties associated with other methods for indirectly assessing fish trophic level and procurement. Several isotopes may be measured but carbon isotopes ratios (^{13}C to ^{12}C; $\delta^{13}C$) which show variation with temperature and salinity and nitrogen ratios (^{15}N to ^{14}N; $\delta^{15}N$) with trophic level are perhaps the most useful (Figure 2).

Nitrogen isotope variation and changes in trophic level

Nitrogen stable isotopes have been particularly useful for tracking changes in the diet of marine predators (Wainright *et al*., 1993; Hirons *et al*., 2001). In the North East Atlantic

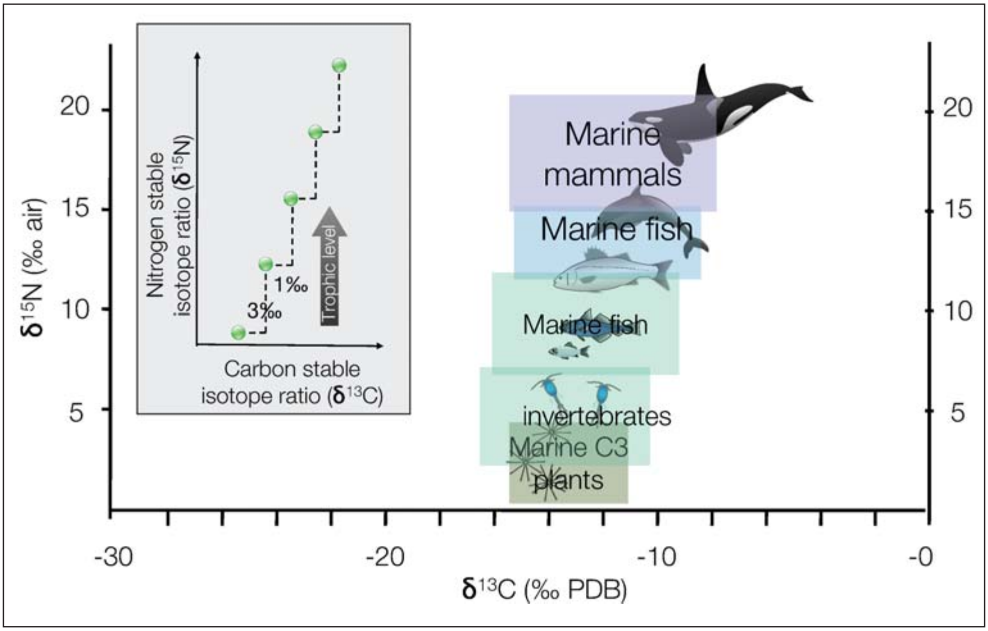


Figure 2. Illustration of the trophic shift in marine systems – increasing by 3‰ in δ^{15}N, and 1‰ in δ^{13}C). Long food chains lead to significant enrichment in δ^{15}N, and shortening of the food chain should lead to a reduction in the δ^{15}N value of the top predators in an ecosystem.

fisheries, statistics indicate that smaller individuals and species have become increasingly abundant in catches over the last 50 years. Essentially, long-lived carnivorous bottom fish of high trophic level have been replaced by short-lived invertebrates and planktivorous pelagic fish of low trophic level. Pauly *et al.* (1998) have described such disturbances of ecosystem structure and function as "fishing down the foodweb". However, a more complete understanding of this process is hampered by the limited data available (Polunin and Pinnegar, 2002). Records of fishery landings and fish dietary data are infrequently kept over periods greater than fifty years and usually only describe a limited geographical region; even in exceptional cases, detailed records rarely extend into the 19th century (Thurstan *et al.*, 2010). Nitrogen isotope ratios, as measured by the ratio of ^{15}N to ^{14}N relative to a standard (δ^{15}N) show clear enrichment of ^{15}N (~2–4‰) in the tissues of a consumer organism relative to its prey, and hence progressive enrichment of ^{15}N with increasing trophic level. Any tendency to fish down the food web should show up as a progressive reduction in the δ^{15}N value. Comparing prehistoric, historic and modern nitrogen isotope data should therefore provide valuable insights into temporal trends in ecosystem structure in relation to recent human impacts. Apparent changes in the nitrogen isotopes of predator species may be linked to long-term environmental changes that have affected organisms at the base of the food web. In order to demonstrate shortening of the food web due to overexploitation, it is essential to compare δ^{15}N measurement of organisms at different trophic levels and at different time periods and in different geographic locations.

Isotope studies to identify fish migration patterns
A range of isotopes can be used to explore migration patterns. Strontium 87/86 varies as a consequence of the underlying geology and can therefore differ between watersheds. Carbon and nitrogen isotopes vary both spatially and temporally as a consequence of primary productivity, temperature, salinity, complexity of the food chain and eutrophication Oxygen and hydrogen isotopes are a reflection of water mass and diet. Examples of the use of isotopes to investigate fish migration include the use of strontium isotopes (Koch *et al*., 1992) to study anadromous fish, and carbon and nitrogen isotopes to investigate migrating cod (McCarthy and Waldron, 2000).

Archaeological isotopic studies
Bone collagen is chosen as the best substrate for analysis in archaeological specimens as it survives well and is not affected by diagenesis. Analysis of the light stable isotopes in fish bone collagen can reveal the animal's main dietary protein sources whilst the tissue was forming. This technique offers the possibility of bypassing some of the uncertainties associated with other methods for indirectly assessing fish trophic level and procurement. Several isotopes may be measured but carbon isotopes ratios (^{13}C to ^{12}C; $\delta^{13}C$) which show variation with temperature and salinity and nitrogen ratios $\delta^{15}N$ with trophic level (above) are perhaps the most useful as they are simple to measure in bone collagen which is minimally affected by diagenesis (Dobberstein *et al*., 2009). The quantities of collagen required for carbon and nitrogen isotope analysis are relatively small (ca. 1-5 mg) albeit larger than required for mass-spectrometry (below).

Isotope variation and change in procurement
An important question in assessing how marine fish were exploited in the past is to look at where they were procured from and changes in their consumption. Whilst carbon isotope analysis ($\delta^{13}C$) of human bone collagen has been used successfully to assess large-scale changes in marine food consumption (Tauber, 1981; Barrett *et al*., 2001; Richards *et al*., 2003), analysis of fish bone may also provide insight into where fish were originally procured; i.e. prior to their trade or exchange and eventual deposition at archaeological sites. Both carbon and nitrogen isotopes have been shown to spatially differentiate modern fish populations (e.g., Deutsch and Berth, 2006) based on the relationship with both diet and the environment (albeit signals display long-term secular variation). By selecting single species of fish or known age and size, then environment (particularly its temperature and salinity) should partially control for any isotopic variation. With the major proviso that decadal and longer range variations fluctuations in isotope values within different water masses remain small and do not drift isotope variation should be able to be related to geographical origin. Following this rationale, carbon isotope analysis of Northern European medieval cod bones has tentatively revealed that preserved cod may have been transported from Arctic Norway to the Baltic at the end of the first millennium AD (Barrett *et al*., 2008). By linking trade routes to centres of consumption and by determine scales of consumption, isotopic studies, combined with fish identification (and better still, population markers), have the potential to highlight and quantify some of the major human impacts on marine stocks over long-time scales.

Identification

Modern fish

There is an increasing need to identify fish tissues to species level; food scientists aim to authenticate the taxonomic origin of processed fish products, and ecologists and fisheries managers require detailed knowledge of predator prey interactions.

Almost all commercially exploited marine fish populations employ a reproductive strategy known as "bet hedging" whereby adults are extremely fecund, but do not invest any resources in parental care. A female cod, for instance, may produce more than 20 million eggs in each spawning season, but after spawning, eggs and larval fish are at the mercy of environmental and ecological processes. Mortality is extremely high in these juvenile fish, and small changes in the rate and extent of marine mortality therefore control population sizes of adult fish. The earliest stages of life are the most critical in this regard. Occasionally, environmental and ecological factors combine to produce optimal conditions for fish survival while eggs and larvae are in surface waters. In these years relatively large numbers of juveniles will survive to adulthood, and the year class produced will dominate adult populations until the next fortuitous set of environmental conditions. This reproductive strategy maintains stable population sizes as long as the period between "bumper years" is relatively short compared to the life cycle of the fish.

The principle cause of mortality of eggs, larvae and juvenile fish is predation. Small changes in the extent of predation on juveniles of commercial species thus have the potential to exert far more control on the size of adult populations than large interventions in fishing effort. Unfortunately, assessing the extent of predation on juvenile fish of any given species is challenging, as they are difficult to identify within predator stomachs. Predation is therefore a weak link in fisheries ecosystems models, complicating predictions of recruiting fish populations (the basis for fisheries stock assessments and quota assignments).

Archaeological identification

Traditional zooarchaeological analysis can be an imprecise science: identification rates and taxonomic precision can vary greatly between specialists. Otoliths are frequently used by fisheries biologists to investigate many aspects of modern fish populations, and although there has been some success applying these methods to archaeological data (e.g., Van Neer *et al.*, 2002), these methods typically have only limited application to archaeological remains because of poor preservation or fragmentation.

Identification of bone is more challenging. A comparison of "blind" testing among experts (Gobalet, 2001) suggests that zooarchaeologists are by no means consistent in their identifications. Leaving aside the difficulties of obtaining modern comparative fish of sufficient size, identification within certainly families can be problematic. The bones of some *taxa* can be particularly difficult to identify to species. For example, within the carp family, only the infrapharyngeal can routinely be identified to species level – yet identification to species of all fragments would allow inferences to be drawn regarding fishing methods, dietary preferences, the health of marine and freshwater ecosystems, and, in the case of the common carp (*Cyprinus carpio* L.), the introduction and spread of medieval fish farming (Hoffmann, 1994).

Fish scales can also be notoriously difficult to identify to species or even family; yet, because one fish contains a great number of them, they can be among the most common of fish remains found on archaeological sites. They have been used to track decadal shifts in anchovy and sardine (and sockeye salmon) stocks (Finney *et al.*, 2002) over the course of millennial time scales. However, although some scales can be identified to broad taxonomic levels, this substantial resource is often completely ignored.

Alternative methods of identification

Microscopy

In the case of animal feed, many of the samples have been variably heat-treated, whilst processing has reduced the remains to bone particles. Skilled microscopists can discriminate fish from non-fish bone fragments (De la Haba *et al.*, 2007) resulting in an internationally validated method (Classical microscopy protocol: Commission Directive 2003/126/EC). This method is implemented as part of wider range of technologies to detect fish and other bone particles in animal feed (see van Raamsdonk *et al.*, 2007 for review), however it cannot discriminate between fish species. Detailed histology has been used by archaeologists (Cuijpers and Lauwerier, 2008) to discriminate between paired species, but these methods have not been applied to fish.

Molecular methods

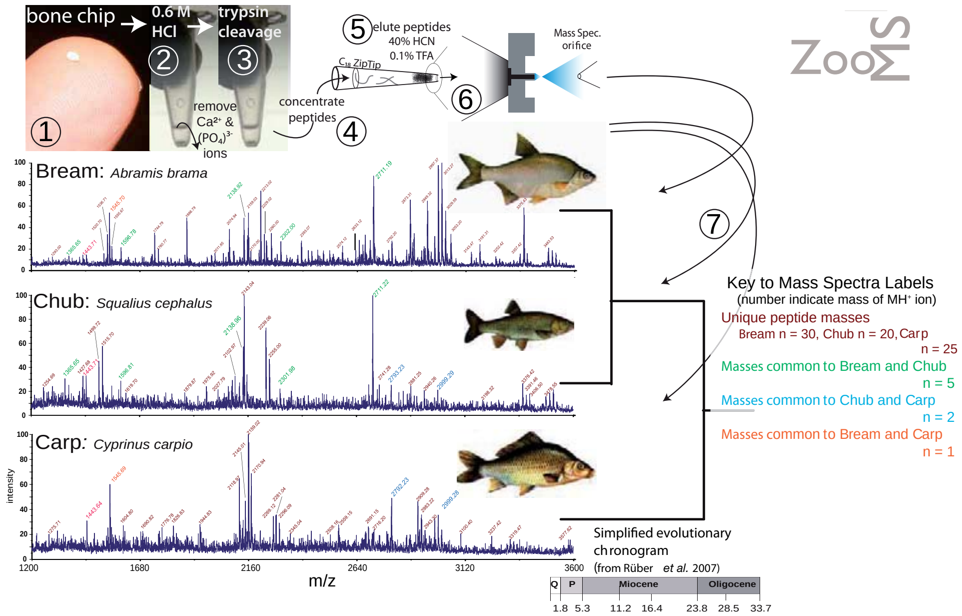
A range of non-morphological methods have been developed to identify archaeological bone fragments including immunology (Lowenstein *et al.*, 2006) and this is offered as a commercial service (pRIA, http://www.videoem.com/pria). Despite their use in foodstuffs, no immunological test kit has yet been commercialized for fish, probably because of the potentially large number of species that might be involved (Mackie *et al.*, 1999). Instead researchers are now investigating the potential of DNA and protein mass-spectrometry based methods (Carrera *et al.*, 2007). The same is true in archaeology, and the most significant recent development has been the use of DNA base methods (Yang *et al.*, 2004; Speller *et al.*, 2005; Desse-Berset, 2009; Pagès *et al.*, 2009).

DNA sequences provide an unambiguous method of discriminating fish bones. However, the survival of aDNA is affected by the thermal history of the site (Poinar and Stankiewicz, 1999; Smith *et al.*, 2003). DNA based methods have threfore proved less successful on older samples from warmer climates (Hlinka *et al.*, 2002). Protein based identification is an alternative method, which offers promise for a lower cost method for identification of older fish bone.

ZooMS; peptide rather than DNA fingerprints?

Collagen, which has been successfully used for stable isotope studies, can also be used for identification. This forms the basis of our novel method for identification of samples; Zooarchaeology by Mass Spectrometry (ZooMS) (Figure 3). DNA fingerprinting uses enzymes to cut DNA at specific sites, revealing differences in sequence as differences in mass. ZooMS works in the same way, but uses bone collagen. ZooMS works by cutting the collagen into a series of peptides and uses the differences between peptide masses, measured by mass spectrometry to identify fish species, in much the same way that DNA fingerprints are used to detect individuals. Unlike DNA, which is present often in vanishingly small quantities, and can easily be contaminated, collagen *is* the bone or fish scale. There is no need to amplify the signal and the masses can be measured at a rate of one sample every few seconds. As well as reducing the risk of contamination, lack of an amplification step, reduces time and cost. It is also possible to identify the presence of different species in a mixture. Blind tests of powdered mixed bone meal autoclaved for 20 minutes at 146ºC (equivalent to ageing for 90000 years at 10°C) identified components present in >5% of the sample in 16/16 samples prepared by the Veterinary Laboratories Agency.

The amounts required for ZooMS are so small that they are difficult to grasp (both literally and metaphorically). The equivalent of 2mm cube of bone (50 mg) suffices even when collagen has fallen to 0.1% of modern levels. We are now working on 250 µm particles and single fish scales.



(1) Bone chip (fingertip for scale) is (2) dissolved overnight (0.6 M HCl, 4°C), supernatant is disgarded (note collagen pellet at base of tube) and (3) trypsin is incubated in bu'er (37°C, 4 hrs). The digested gelatin peptides are (4) concentrated onto a C18 ZipTip, following rinsing, (5) gelatin peptides are eluted (40% HCN in 0.1% TFA) either onto (6) MALDI plate or via Nanomate into ESI interface. The Peptide Mass Fingerprints for each chip (7) are used to identify cyprinids. Note that in the three bone chips analysed very few of the peptide masses are shared between any of the cyprinids, suggesting multiple marker peptides will be present.

Figure 3. A summary of the ZooMS (Zooarchaeology by mass-spectrometry) method.

Summary

Both modern fish ecologists and archaeologists are turning to the same molecular tools. Not all tools work as well in archaeological materials as their modern counterparts: DNA can be present but degrades relatively rapidly. Mineral apatite undergoes rapid diagenetic alteration, exchanging elements with the burial environment and shifting both trace element and isotopic compositions. Bone collagen continually degrades and is progressively lost from bone, but whilst still present appears to hold a reliable series of molecular records, both to identify the bone and to explore details of trophic status and (to a degree) geographic origin.

Bibliography

Barrett J.H., Beukens R.P., and Nicholson R.A. (2001). Diet and ethnicity during the Viking colonization of northern Scotland: evidence from fish bones and stable carbon isotopes. Antiquity 75: 145-154.

Barrett J., Johnstone C., Harland J., Van Neer W., Ervynck A., Makowiecki D., Heinrich D., Hufthammer A., Enghoff I., Amundsen C., Christiansen J., Jones A., Locker A., Hamilton-Dyer S., Jonsson L., Lõugas L., Roberts C., and Richards M. (2008). Detecting the medieval cod trade: a new method and first results. Journal of Archaeological Science 35: 850-861.

Barrett J., Nicholson R., and Cerón-Carrasco R. (1999). Archaeo-ichthyological evidence for long-term socioeconomic trends in Northern Scotland: 3500 BC to AD 1500. Journal of Archaeological Science 26: 358-388.

Burger C., Zhou H.W., Wang H., Sics I., Hsiao B.S., Chu B., Graham L., and Glimcher M.J. (2008). Lateral packing of mineral crystals in bone collagen fibrils. Biophysical Journal 95: 1985-92.

Carrera M., Cañas B., Piñeiro C., Vázquez J., and Gallardo J.M. (2007). De novo mass spectrometry sequencing and characterization of species-specific peptides from nucleoside diphosphate kinase B for the classification of commercial fish species belonging to the family Merlucciidae. Journal of Proteome Research 6: 3070-80.

Cuijpers S., and Lauwerier R. (2008). Differentiating between bone fragments from horses and cattle: a histological identification method for archaeology. Environmental Archaeology 13: 165-179.

De la Haba M., Pierna J., Fumiere O., Garrido-Varo A., Perez-Marin J.G.D., Dardenne P., and Baeten V. (2007). Discrimination of fish bones from other animal bones in the sedimented fraction of compound feeds by near infrared microscopy. Journal of Near Infrared Spectroscopy 15: 81-88.

Desse-Berset N. (2009). First archaeozoological identification of Atlantic sturgeon (*Acipenser oxyrinchus* Mitchill 1815) in France. Comptes Rendus Palevol 8: 712-714.

Deutsch B., and Berth U. (2006). Differentiation of western and eastern Baltic Sea cod stocks (*Gadus morhua*) by means of stable isotope ratios in muscles and otoliths. Journal of Applied Ichthyology 22: 538-539.

Dobberstein R., Collins M., Craig O., Taylor G., Penkman K., and Ritz-Timme S. (2009). Archaeological collagen: Why worry about collagen diagenesis? Archaeological and Anthropological Sciences 1: 31-42.

Enghoff I., Mackenzie B., and Nielsen E. (2007). The Danish fish fauna during the warm Atlantic period (ca. 7000–3900 bc): Forerunner of future changes? Fisheries Research 85: 285-298.

Finney B.P., Gregory-Eaves I., Douglas M.S.V., and Smol J.P. (2002). Fisheries productivity in the northeastern Pacific Ocean over the past 2,200 years. Nature 416: 729-33.

Gobalet K.W. (2001). A critique of faunal analysis; inconsistency among experts in blind tests. Journal of Archaeological Science 28: 377-386.

Hirons A., Schell D., and Finney B. (2001). Temporal records of d 13 C and d 15 N in North Pacific pinnipeds: inferences regarding environmental change and diet. Oecologia 129: 591-601.

Hlinka V., Ulm S., Loy T., and Hall J. (2002). The genetic speciation of archaeological fish bone: a feasibility study from southeast Queensland. Queensland Archaeological Research 13: 71-78.

Hoffmann R. (1994). Remains and verbal evidence of carp (*Cyprinus carpio*) in medieval Europe. 7th Meeting of the ICAZ Fish Remains Working Group. Fish exploitation in the past, 6-10 Sep 1993 Leuven (Belgium): Annales-Musee Royal de l'Afrique Centrale-Sciences Zoologiques (Belgium); Annalen-Koninklijk Museum voor Midden-Afrika-Zoologische Wetenschappen.

Koch P.L., Halliday A.N., Walter L.M., Stearley R.F., Huston T.J., and Smith G.R. (1992). Sr isotopic composition of Hydroxyapatite from recent and fossil salmon - the record of lifetime migration and diagenesis. Earth and Planetary Science Letters 108: 277-287.

Lowenstein J.M., Reuther J.D., Hood D.G., Scheuenstuhl G., Gerlach S.C., and Ubelaker D.H. (2006). Identification of animal species by protein radioimmunoassay of bone fragments and bloodstained stone tools. Forensic Science International 159: 182-188.

Mackie I.M., Pryde S.E., Gonzales-Sotelo C., Medina I., Perèz-Martìn R., Quinteiro J., Rey-Mendez M., and Rehbein H. (1999). Challenges in the identification of species of canned fish. Trends in Food Science & Technology 10: 9-14.

Mccarthy I.D., and Waldron S. (2000). Identifying migratory *Salmo trutta* using carbon and nitrogen stable isotope ratios. Rapid Communications in Mass Spectrometry 14: 1325-1331.

O'day S., Van Neer W., and Ervynck A. (2002). Behaviour behind bones: the zooarchaeology of ritual, religion, status and identity. Proceedings of the 9th ICAZ Conference, Durham 2002. Oxbow Books Ltd. 350 pp.

Pagès M., Desse-Berset N., Tougard C., Brosse L., Hänni C., and Berrebi P. (2009). Historical presence of the sturgeon *Acipenser sturio* in the Rhône basin determined by the analysis of ancient DNA cytochrome b sequences. Conservation Genetics 10: 217-224.

Pauly D., Christensen V., Dalsgaard J., Froese R., and Torres F. Jr. (1998). Fishing Down Marine Food Webs. Science 279: 860-863.

Poinar H.N., and Stankiewicz B.A. (1999). Protein preservation and DNA retrieval from ancient tissues. Proceedings of the National Academy of Sciences of the United States of America 96: 8426-8431.

Polunin N., and Pinnegar J. (2002). Trophic ecology and the structure of marine food webs. Handbook of Fish Biology and Fisheries 1: 301-320.

Richards M.P., Schulting R.J., and Hedges R.E.M. (2003). Sharp shift in diet at onset of Neolithic. Nature 425: 366-366.

Rick T., and Erlandson J. (2008). Human impacts on ancient marine ecosystems: a global perspective. Rick T.C. and Erlandson J.M. (Eds.), University of California Press. 336 pp.

Roberts C. (2007). The unnatural history of the sea. Island Press. 456 pp.

Smith C.I., Chamberlain A.T., Riley M.S., Stringer C., and Collins M.J. (2003). The thermal history of human fossils and the likelihood of successful DNA amplification. Journal of Human Evolution 45: 203-217.

Speller C., Yang D., and Hayden B. (2005). Ancient DNA investigation of prehistoric salmon resource utilization at Keatley Creek, British Columbia, Canada. Journal of Archaeological Science 32: 1378-1389.

Tauber H. (1981). 13C evidence for dietary habits of prehistoric man in Denmark. Nature 292: 332-333.

Thurstan R.H., Brockington S., and Callum M.R. (2010). The effects of 118 years of industrial fishing on UK bottom trawl fisheries. Nature Communications.

Van Neer W., Ervynck A., Bolle L., and Millner R. (2002). Fish otoliths and their relevance to archaeology: an analysis of medieval, post-medieval, and recent material of plaice, cod and haddock from the North Sea. Environmental Archaeology 7: 61-76.

Van Raamsdonk L., Von Holst C., Baeten V., Berbenc G., Boixb A., and Jong J.D. (2007). New developments in the detection and identification of processed animal proteins in feeds. Animal Feed Science and Technology 133: 67-83.

Wainright S., Fogarty M., Greenfield R., and Fry B. (1993). Long-term changes in the Georges Bank food web: trends in stable isotopic compositions of fish scales. Marine Biology 115: 481-493.

Wheeler A., and Jones A.K.G. (1989). Fishes. Cambridge manuals in archaeology. University Press (Cambridge). Reports from the EAU, York. Report 94, pp. 54-54.

Yang D.Y., Cannon A., and Saunders S.R. (2004). DNA species identification of archaeological salmon bone from the Pacific Northwest Coast of North America. Journal of Archaeological Science 31: 619-631.

ECOLOGY AS AN HISTORICAL DISCIPLINE

Ferdinando Boero
DiSTeBA - University of Salento, Lecce (Italy)
e-mail: boero@unisalento.it

Key-words: *ecology, physics, physics envy, modeling, ecological predictions, history*

Abstract

The differences between a-historical and historical disciplines are described. Ecology is depicted as an historical science, governed by both constraints and contingencies, being only weakly predictable.

Darwin's feathers

The Origin of Species (Darwin, 1859) is the founding pillar of the modern theory of evolution. Evolutionary biology reconstructs the history of life (through paleontology) and identifies how life changed during its history (with ecology, genetics, etc.), so being an exquisitely historical discipline.
Darwin (1959) explains with a very effective sentence the difference between historical and a-historical systems: "*Throw up a handful of feathers, and all must fall to the ground according to definite laws. But how simple is this problem compared to the action and reaction of the innumerable plants and animals which have determined, in the course of centuries, the proportional number and the kinds of trees...*"
It is evident that Darwin refers to the theory of universal gravitation that started with Copernicus, continued with Galileo, to be eventually refined by Newton. The laws governing the interaction between bodies of different size (like stars and planets, or a planet and much smaller bodies) can be mathematized, and can lead to precise predictions about the results of the interactions. No matter how many times we reproduce these interactions, the result will always be the same. Especially if there are no external disturbances. If Darwin's feathers would have been thrown in the air during a hurricane, the laws governing their falling down to the ground would have been much more cumbersome than if they would have been thrown up under experimental conditions, for instance in a conditioned room with no air currents. Under hurricane conditions, probably no calculation would lead to predict the falling down of Darwin's feathers, whereas in a controlled room their behavior would be easily predictable.
The hurricane is history, as would also be the opening of a door of the controlled room during the experiment. History is change with time, and Darwin makes it clear speaking about *the course of centuries*.

The action and reaction of the innumerable plants and animals in the course of centuries is simply ecological history, and it eventually results into evolution. All this is then to be coupled with changes in physical conditions, such as climatic change, continental drift, and with human action and all the other disturbances that might interfere with the action and reaction of plants and animals (not to speak about protists, bacteria and fungi).

Hard vs. soft sciences

Hard sciences use mathematics, soft sciences tell stories. The distinction might derive from Kant's claim that "*in any special doctrine of nature there can be only as much proper science as there is mathematics therein*" (Kant 1786-2004, p. 6). In other words, the more our approach to the understanding of nature is mathematized, the more it is scientific. The laws of physics are mathematized and allow to give values to the measured variables and to make them interact with each other so that, measuring them at time zero, we can predict their values at time one. The position of the feathers can be measured before throwing them up, then the force of throwing can be measured, and its direction, leading to predict where and when the feather will fall. We can repeat the same action one million times, and for one million times the result will be the same. There is no history in all this. And mathematics completely rules reality, allowing for its understanding and for its prediction. Of course, with quantum physics, these triumphant assumptions are not justified, but at our scale of perception they surely are.
Now introduce history in this system, introduce the vagaries of human behavior and of meteorology and climate. Throw the feathers up in the real world. The number of rules that regulate their behavior becomes intractably high. It is true that each of the forces that act on the feather could be measured in a given moment, but it is also true that Heisenberg's principle of uncertainty (Heisenberg, 1927) tells us that the more we know about the position of a feather the less we know about its velocity, and vice versa. While things are happening, strange things can happen, we can freeze history so to analyze it (to know the position), but then we loose contact with the events (to know the velocity).
If the bodies that interact are more than two, furthermore, their future behavior (i.e., the history of their system) is inherently unpredictable (Poincaré, 1890). Inherent unpredictability is also postulated, and mathematically demonstrated, by chaos theory (Lorenz, 1963).
Going back to Kant, it is now evident that the systems that can be studied with mathematics are simple ones, those that are tackled by classical physics. Quantum physics tells us that precision is impossible even in these systems, but we can disregard this problem in our everyday life. Elevators function. They might not function exactly in the same way, every time they bring us up or down, but we do not care much about the little mistakes that would trouble a quantum physicist. When the number of interacting bodies increases, and the number of interactions increases further, however, even our scale of perception is disturbed, and the mathematization of the interactions does not lead to the expected results. We can go back to the second part of Darwin's sentence, and look at it through the uncertainty principle, the problem of the three bodies, and chaos theory. *The action and reaction of the innumerable plants and animals which have determined, in the course*

of centuries, the proportional number and the kinds of trees... is inherently unpredictable, and even if we can extract each action and reaction from the system, and try to measure them under experimental conditions, once we assemble the various parts we would lose our powers of understanding. Aristotle, three centuries Before Christ, already warned that the whole is more than the sum of the parts. It is tenuous to understand each component and hope to understand the whole.
In this framework, the hard sciences are the easy ones, and can be mathematized, whereas the soft ones are the difficult ones, where mathematics is not so powerful.

Physics envy in historical sciences

Physics envy regards the practitioners of soft sciences who would like their disciplines to become hard. Economics is one of these disciplines (Mayer, 1980) and several Nobel prizes in economics built a heavily mathematized way to deal with human affairs, promising a forecast power that was evidently overly optimistic. Their failure is exemplified by the mismanagement (and failure) of world economy due to the blind application of their approach. Also ecology suffers for physics envy (Egler, 1986). The application of physics reductionism, very powerful for simple, a-historical systems, is aimed at removing history from historical systems, reducing them into a-historical domains. In doing so, however, their properties are conceptually changed and the obtained results do not fit with the features of the real systems.

Contingencies and constraints

The rules of physics are nothing else than constraints to the functioning of any system. Identifying the constraints allows formulating laws. A law is a rule that is universally valid: if a law is known, its application leads to predictions of the type: *if... then*. *If* the initial conditions are these, and I apply this force, *then* future conditions will be these. In chaos theory the laws are not so strict, but they are there anyway. They are called attractors. An attractor is, more or less, a constraint that forces a system to remain into a definite set of possibilities (winters are cold, summers are hot). In a way, attractors incorporate Heisenberg's indetermination into classical physics. They decrease the precision of physical laws, still leaving the possibility of making some predictions, albeit imprecise. In historical systems, contingencies are the other face of the medal. They still make the system move within the limits of attractors, but determine the imprecision of any forecast on their behavior. Contingencies can also draw a constrained system into a different direction, eventually changing the shape of its attractors.
In a way, when identifying constraints, we identify the regularities in the behavior of a system, whereas the identification of contingencies leads to the identification of irregularities. In chaos theory, the popularized message is that the beat of the wings of a butterfly in a place can cause a hurricane at another place. The claim is very suggestive, but butterfly wing beats usually do not cause much trouble. It might happen, however, that one of them might become the straw that broke the camel's back.

Regularities and irregularities

Our aesthetic perceptions are often based on regularities: we are attracted by them, also conceptually. We like to be able to predict what will happen, and regularities allow us to do so, reinforcing our self-esteem. If the world were made just of regularities, however, it would be a very boring place, and things would proceed indefinitely along the same path, over and over again. The world is not boring because of irregularities and, as claimed by Boero *et al.* (2008) "irregularities rule the world (sometimes)". Regularities and constraints, together with irregularities and contingencies concur to define history, they are all relevant to the understanding of the world. Physics envy, the quest for hardness in science, led to study more the regularities and the constraints than the irregularities and the contingencies, the softeners of any science.

What historians do

Historians have two main goals. They must reconstruct the events of the past (history) and they should identify what caused them. Put in scientific jargon, they reconstruct historical patterns, and then identify the processes that generated them. Historians collect information, refer it to a period, assemble it and reconstruct past conditions (historical patterns and processes). Of course, their approaches can be biased and they can misidentify the drivers of history. In some cases, for instance, history can be seen as a sequence of powerful individuals (kings, emperors, generals, politicians) that, with their deeds, generate historical patterns. History can also be seen in terms of technology, from the production of fire, to the wheel, the use of Arabic numbers, writing, agriculture, the discovery of new continents, the invention of weapons and computers and so on. In a way, these technological advancements changed the attractors of history: kings and emperors did what they did simply because they were backed by these technologies. History might also be seen as a sequence of impacts by humans on their environment, with a sequence of ecological collapses that caused the wars constellating our history.
Of course all these ways of looking at history do have their value and, together, concur to delineate what happened in the past.

Predictive history

Can we obtain information about the future from information about the past? In a way yes, since we can learn from the past that, for instance, all empires fell, besides the ones surviving in the present time. However, we know that their duration varied, and there is no general rule about how long an empire will last. Some were linked to a person, like the Empire of Gengis Kahn (and his son and grandson), others to a system, like the Roman Empire. Of course we can learn, by comparing these two extremes, that if an Empire is based on person(s), then its life will be short, being constrained by the biological limits of human life, whereas if it is based on a system, its life might be longer. But the short duration and the fell of the USSR (1917-1991), based on a system and not on a single

person, shows that general historical laws are not available: history is inherently unpredictable. The business of historians is not to predict future history.
The predictive side of history, in fact, is not labeled as history, it is economics and we have already seen that it went through a series of failures, since it promised the impossible.
Economics promises knowledge about the future, history promises wisdom about the future.

Ecological history

Ecology, as a hard science, dedicated much effort at identifying laws and regularities, with the aim of becoming predictive. Predictive ecology, in fact, might be a very precious tool for the management of ecosystems. It would be wonderful, in fact, if we were able to predict that *if* we perform a given action, *then* the situation will change in a definite way. If this were possible, we would be greatly advantaged, just as we would be if this procedure were possible with economics. Unfortunately ecological and economic systems are very sensitive to contingencies and their attractors are feeble.
Besides measuring some variables, trying to find then algorithms predicting their interaction, or magic numbers that describe their behavior in the future, we might also treat these disciplines for what they are, giving up transforming them into a-historical sciences and surrendering to their historical nature.
Of course, ecology provides a powerful conceptual toolkit that allows identifying ecological patterns and processes. This toolkit can allow the description of current ecological situations at a given place of any size, from a single spot to an ecoregion.

Proximate vs. ultimate drivers of change

Once we have described an ecological situation, we can try to understand what is keeping it the way it is, what are the drivers that led to its establishment and what are the drivers that keep it stable or that make it change in a regular way. These drivers are both proximate (coastal erosion is due to wave action on coastal sediments) and ultimate (the barrage of rivers and reforestation led to lower sediment inputs through rivers, with lower possibilities of natural beach replenishment). Both ultimate and proximate drivers are important, and are strongly correlated with erosion. The erosion process, thus, is due to multiple causes, acting at multiple temporal and spatial scales. And all these scales concur at determining it.

Adriatic Ecological History

In the past, before the Eighties, the Adriatic was the most productive sea of the whole Mediterranean, due to strong nutrient influxes deriving from the Po River. Today the Adriatic Sea is in distress, and the yield of fisheries, the main measure of its productivity, is not as high as it was before, especially when comparing the efficiency of today's fishing

gear, with that of 30 years ago. Looking at today's situation, one might ask what drivers did determine it. Boero and Bonsdorff (2007) depicted Adriatic Ecological History as a sequence of periods. The high-production period ended in the early Eighties, when the Sea was affected by the swarms of the jellyfish *Pelagia noctiluca*. The jellyfish period was followed by a red tides period, caused by dinoflagellate blooms. Meanwhile, also anoxic crises characterized the northern part of the basin, and fisheries became more and more efficient. For instance, benthic mollusks declined, and started to be harvested by hydraulic dredges, until the local species declined, to be intentionally replaced by tropical species. After the red tides, the Adriatic was characterized by mucilage events.
The system shifted from being characterized by vertebrate-dominated populations (fish), to invertebrate-dominated ones (jellyfish), to protistan-dominated ones (dinoflagellates producing red tides), to moneran-dominated ones (bacteria producing mucilage). At present, these events are occurring in rapid succession, almost every year, and the system is not as productive as it was before.
All these events have been studied in isolation, and only their proximate causes have been considered. Boero and Bonsdorff (2007) proposed that the *Pelagia* years were the trigger of this change in the functioning of the Adriatic Sea, since the predation of this jellyfish disrupted the structure of the ecosystem, simplifying it and leading to its degradation.

Conclusion

Realizing that ecology is an historical discipline should not lead to the dismissal of a-historical approaches. They are very important, as it is important to try, anyway, to produce predictive models of our ecosystems. It is also important, however, to reconstruct their ecological history and, using the insight gained by the proximate approaches, try to understand the ultimate causes that led ecosystems in the state of today, also to depict scenarios about their future. Ecological predictions can be only weak and imprecise, mathematics is often too simple to perform them, and it would give anyway an allure of precision that is only an illusion, as were the precise predictions of Nobel-Prize-winning economists.
(Hi)story-telling science has been ridiculed by mathematically oriented scientists, and now it is their turn to be labeled as future tellers with a turban and a crystal ball. Both approaches, however, are fruitful and (hi)story tellers must not repeat the mistake of crystal ball scientists. Hard and soft sciences can happily co-exists, each with its own dignity, reinforcing each other by reciprocally supplementing our attempts to understand the world.

Bibliography

Bennis W.G., and O'Toole J. (2005). How business schools lost their way. Harvard Business Review 83(5): 96-105.
Boero F., and Bonsdorff E. (2007). A conceptual framework for marine biodiversity and ecosystem functioning. Marine Ecology 28(Suppl. 1): 134-145.

Boero F., Bouillon J., Gravili C., Miglietta M.P., Parsons T., and Piraino S. (2008). Gelatinous plankton: irregularities rule the world (sometimes). Marine Ecology Progress Series 356: 299-310.

Darwin C. (1859). On the origin of species by means of natural selection. or the preservation of favoured races in the struggle for life. John Murray, London. 502 pp.

Egler F.E. (1986). Physics envy in ecology. Bulletin of the Ecological Society of America 67(3): 233-235.

Heisenberg W. (1927). Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. In Zeitschrift für Physik. 43, S. pp. 172–198.

Kant I. (1786). Metaphisical foundations of natural sciences. Friedman M. (Ed.). Cambridge University Press, Cambridge (printed in 2004). 119 pp.

Lorenz E.N. (1963). Deterministic non periodic flow. Journal of the Atmospheric Sciences 20: 130-141.

Mayer T. (1980). Economics as a hard science: realistic goal or wishful thinking? Economic inquiry 18 (2): 165-168.

Poincarè H. (1890). Sur les équations de la dynamique et le probléme de trois corps. Acta Mathematica 13: 1–270.

THE USE OF LOCAL ECOLOGICAL KNOWLEDGE TO RECONSTRUCT THE HISTORY OF MARINE ANIMAL POPULATIONS. POTENTIALS AND LIMITATIONS

Saša Raicevich[1], Tomaso Fortibuoni[1,2], Gianluca Franceschini[1], Igor Celić[1], Otello Giovanardi[1]
e-mail: sasa.raicevich@isprambiente.it

Key-words: *Local Ecological Knowledge, Fishermen Ecological Knowledge, Shifting the Baseline Syndrome*

Abstract

Local Ecological Knowledge (LEK) is an emerging tool in the study of recent trends of marine animal populations. In particular, fishermen are deemed to be the repository of a large amount of valuable information regarding both species' ecology and their fluctuations in time and space, as well as on the development of fishing activities, including changes over time in technical features and yields. Indeed, the availability of this information is fundamental when comparing the present status of marine resources to their previous one. In this paper, the theoretical basis and practical approach to be applied when collecting and analysing LEK are introduced and discussed basing on recent literature and selected case-studies.

Introduction

Marine ecologists and fishery scientists have recently acknowledged the need of rediscovering an historical perspective when studying long-term changes in the marine environment (e.g., Jackson *et al.*, 2001; Pandolfi *et al.*, 2003; Rosenberg *et al.*, 2005; Sàenz-Arroyo *et al.*, 2006; Bolster, 2006; Lotze *et al.*, 2006; Ainsworth *et al.*, 2008; Lotze and Worm, 2009). According to several authors, the present status of marine environment and its biological resources is the result of profound changes that were historically driven by anthropogenic sources of disturbance (e.g., fisheries, pollution, eutrophication, habitat disruption, etc) and natural fluctuations (Jackson *et al.*, 2001; Lotze *et al.*, 2006; Cardinale *et al.*, 2010). This issue was for the first time raised by Daniel Pauly who, in his note entitled "Anecdotes and the shifting baseline syndrome of fisheries" (1995), highlighted that the recent rate of change in marine biodiversity should be so high that the percep-

1 ISPRA - Italian National Institute for Environmental Protection and Research, Chioggia (Italy).
2 OGS - National Institute of Oceanography and Experimental Geophysics, Trieste (Italy).

tion of its present-day status in young marine biologists would be quite dissimilar (and simplified) compared to the perception of researchers belonging to previous generations. This fact implies the so-call "shifting baseline syndrome" (SBS) and the need of reconstructing historical baselines for fishery resources and, in general terms, for marine biodiversity.

Stemming from these considerations, marine historical ecology is now an emerging research discipline in marine science (Bolster, 2006; Lotze and Worm, 2009). In its framework, the main difficulty faced by ecologists is the retrieval, validation, integration and analysis of historical data. Indeed, the systematic collection of data on marine biota with a sound methodological approach dates back only to the last few decades, while quantitative data related to the former period are less common (Jackson *et al.*, 2001; Pitcher, 2001; Lotze and Worm, 2009). For instance, fishery statistics might be available for commercial species at least since the early 1950 but these data, although valuable, have intrinsic limitations being fishery-dependent (Watson and Pauly, 2001; Pauly and Palomares, 2005). Thus, their standardization is not straightforward, being catches affected not only by stock size, but also by market request, fishing fleet's capacity and effort, as well as different objectives and strategies of skippers, etc. Therefore, in order to investigate historical changes in marine biodiversity a range of other sources should be used, including paleological, archaeological and historical sources (Lotze and Worm, 2009). Accordingly, historical ecology studies are usually characterised by a multidisciplinary approach and may benefit from studies carried out in the framework of both scientific disciplines and humanities (Holm, 2003).

Even considering the most recent period, available data may somehow misrepresent changes in stock abundances (Johannes *et al.*, 2000) and, at the same time, a thorough description of trends in anthropogenic drivers may be missing. For instance, in many areas historical changes in fishing capacity and fishing effort distribution, as well as changes in fishing technology and exploited fishing grounds are little described, thus hampering the capability of scientists to correctly understand patterns, trends, and causality in changes of marine biological resources.

Among the various disciplines that are currently in use to partially fill these gaps of knowledge, an emerging interest has been given to anthropology (the science of human beings in relation to physical character, environmental and social relations, and culture; Garcìa-Quijano, 2007) and ethnobiology (the study of how human cultures interact with and use their native plants and animals; Reyes-García *et al.*, 2006). These disciplines provide a methodological framework to be used to collect, analyse and interpret information gathered from experienced observers such as fishermen, indigenous and local people, whose knowledge can be useful especially in studies dealing with the marine environment and its exploitation, especially in "data poor" systems (Moreno-Báez *et al.*, 2010). While the ecological knowledge empirically acquired by non-scientists has been for a long time disregarded as being merely anecdotal and, thus, intrinsically biased (Pauly, 1995; Mackinson, 2001), recent researches reviewed its application (Mackinson and Nottestad, 1998; Neis *et al.*, 1999; Huintington, 2000; Murray *et al.*, 2006; Ommer *et al.*, 2007; Papworth *et al.*, 2009) showing its value and contribute to historical ecology studies (Berkes *et al.*, 2000; Johannes *et al.*, 2000; Bergmann *et al.*, 2004; Rosa *et al.*, 2005; Sàenz-Arroyo *et al.*, 2005; Murray *et al.*, 2006; Moreno-Báez *et al.*, 2010).

This paper is focussed on the description of the inherent features as well as the potential and limitations of Local Ecological Knowledge (LEK) and its use in marine ecology, with special emphasis paid to Fishermen' Ecological Knowledge (FEK). The aim is to provide general methodological guidelines and insights for its collection and to stimulate its use in the framework of historical ecology studies.

Knowledge, Local Ecological Knowledge and Scientific Ecological Knowledge

The creation of knowledge is a cognitive process (a process of experience and events) that includes memory and recall. In particular, memory has a complex nature and "positive" events are usually more strongly remembered. Human mind uses a variety of heuristic rules to process information from the outside world and people tend to minimise "cognitive dissonance" (negative experience of holding contrary opinion or behaving in a way that is contrary to an opinion held). Accordingly, mental models (interpretation of experiences and events) and beliefs are usually persistent, unless different strong evidences are acquired and, thus, models are revised.

Local Ecological Knowledge (LEK) has been defined as a "body" and "system" of understanding and know-how that arises through time from a variety of individual and shared experiences and observations, mediated by culture, with regards to environmental factors, behavioural attributes and ecological dynamics (Shackeroff and Campbell, 2007). This terminology is often used as a synonymous of Traditional Ecological Knowledge (TEK) that has, however, a slightly different meaning. Indeed TEK, the "cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment", is considered to be "an attribute of societies with historical continuity in resource use practices; by and large, these are non-industrial or less technologically advanced societies, many of them indigenous or tribal" (Berkes, 1993). Thus, the term TEK emphasises those aspects of knowledge acquired through experience and handed down through generation in non-industrial societies (Berkes *et al.*, 2000).

For simplicity, and with the aim of focussing on Ecological Knowledge acquired by local communities without distinguishing on whether these communities are "industrial" or not, in this paper we will use the term LEK, since it is more general and encompasses not only indigenous or tribal knowledge, but also knowledge achieved in "developed" Western countries. For the same reason, we will try to avoid the use of the wording Fishermen's Ecological Knowledge (FEK) when not relevant for the subject matter, in particular when we will discuss the general features of LEK.

There are several relevant differences between LEK and Scientific Ecological Knowledge (SEK, sometimes referred to as "Western" science", see Berkes *et al.*, 2000, and Shackeroff and Campbell, 2007) that must be taken into account when using LEK to inform SEK and for the purpose of their reciprocal comparison and interpretation (García-Quijano, 2007; Rochet *et al.*, 2008).

Indeed, LEK, being embedded in cultural tradition and experience, is acquired by an undefined process and is usually anecdotal, qualitative, and it has local and long-term scales. It lacks of any particular formalism and, most of all, it is human-centred and holistic. On

the contrary, SEK is rooted in the scientific method; therefore, it is based on the hypothesis-testing process using quantitative data collected by means of *ad hoc* experiments. This approach, that is the basis of modern science as it has been introduced by Galileo, attempts the generalization and the provision of "objective" patterns, with the aim of establishing the paradigm that better fits to experimental evidences. Theories will be valid until they are falsified, and thus a new paradigm will be first proposed and then accepted by the scientific community (Khun, 1962). The supposed "objectivity" of science is also reflected in its supposed insensitivity to human concerns.
Due to these inherent differences, it may be questioned whether or nor LEK can inform SEK, or, in other words: *why scientists should care about LEK, if this knowledge is most often not objective, quantitative and standardized?*
A very practical answer might be: it is better then nothing! Or, more formally: in data lacking situations, if the only available information can be obtained by LEK, it is better to collect it rather then not (and before information/data holders are definitively lost as people die). Elsewhere, if there are little data needing corroboration or "side" information to be better used and interpreted, LEK might be the source of these additional information/data (García-Quijano, 2007).
On the other hand, this vision is somehow too simplistic, since both LEK and SEK represent a form of human knowledge and they are both affected by subjectivity; thus they should have, somehow, similar values to our societies (Shackeroff and Campbell, 2007). However, this general mistrust is also rooted in the lack of confidence that scholars belonging to "scientific disciplines" have in relation to evidences and theories belonging to humanities, such as history, anthropology, etc., since they consider these disciplines to be only speculative and thus not "scientifically valid"[3].

LEK potentials and limitations in marine science

As above mentioned, marine ecologists can benefit from a thorough analysis of LEK and in particular from fishermen's experience. Indeed, fishermen have a long-term experience on marine/brackish/fresh water species that, according to their age, can reach up to 60 years before present. At the same time fishing can be considered as an extensive sampling of marine fauna and, thus, fishermen might be considered as expert "samplers" of marine fauna, although "sampling" (i.e., commercial or subsistence fishing) is not carried out by applying an "appropriate" experimental design. The ecological information that can be gathered in this framework ranges from the description of changes in the presence, abundance, size and spatial distribution of species over time to insights on their ecology and behaviour, as well as may include data describing the exploitation of marine resources

3 This problem probably derives from the lack of knowledge on methodologies adopted by humanities scholars; however, I must admit that when I had the chance to get in touch with History of Marine Animal Populations (HMAP) historians, I frequently found their historical reconstructions more sound than some scientific papers that rely only on the presence/absence of statistically significant changes in any environmental variable to derive general, but sometimes not fully discussed or even illogical, conclusions. [S. Raicevich]

(e.g., fishing boats and gears description, fishing effort, etc.). On the other hand, anthropologists and ethnobiologists derive from LEK information on the evolution of human-environment interactions, as well as the ecological knowledge achieved by local communities and fishermen through experience, details on the structure and functioning of fishermen communities, traditions, cultural habits and beliefs.

Before discussing different field approaches to "create" LEK, it is necessary to remark that many limitations, that can be partially overcome by a thorough understanding of LEK inherent features and by the adoption of a methodological framework consistent with the research objectives, might affect the quality of collected information.

First of all, misreporting. Indeed, it is possible that informants (e.g., fishermen) deliberately provide biased information, especially when they suspect that "negative" management consequences (e.g., effort limitation, taxes, etc.) might arise due to interviews contents. On the other hand, they might over report data on catches or species' size in order to appear as better fishermen compared to other colleagues.[4] Eventually, informants may also provide erroneous information due to personal or generational amnesia (Papworth *et al.*, 2009). A more subtle, and often neglected, problem is related to the fact that fishermen's perception of stock abundance may differ from the "real" stock state. This is possible since fishermen's experience is based on commercial fishing activities, and not on *ad hoc* experiments carried out with a proper sampling design. Therefore, observed Catches per Unit of Effort (CPUE; e.g., the number or weight of fish caught per hour of fishing) might be not linearly proportional to stock size (Figure 1). For instance, if fishermen are exploiting an aggregating species and they are able to identify fish shoals, they might experience high catches although stock size is diminishing. This phenomenon is named hyperstability and may occur when there is a density-dependent use of habitats by target species (Hilborn and Walters, 1992; Sadovy and Domeier, 2005). By contrast, when the target species is mainly spread in areas/habitats that are not easily accessible to fishermen, who catch them only occasionally elsewhere, a steep reduction in CPUE might be experienced although the true stock size does not decline significantly (hyperdepletion) (Hilborn and Walters, 1992; Sadovy and Domeier, 2005).

Moreover, CPUE varies according to technological improvements in fishing gears and devices, as well as to changes of fishing grounds and target species, that in turn can be affected by changes in species' profitability. A lack on change in CPUE might be determined by an increase in fishing capacity (technology associated to fishing) rather than by the stability of the exploited stock size (Pauly *et al.*, 2002).

THE PROCESS OF "CREATING" LEK

The collection (or creation, *sensu* Fogerty, 2008) of LEK and its interpretation for scientific purposes is not a straightforward process (García-Quijano, 2007). Approaches and methodologies for documenting LEK are usually conceived in the framework of an anthro-

---

4 Interestingly, we noticed a nice synthesis of this behaviour on a T-shirt from Alaska recreational fishermen, that reinvented the famous proposition from Cartesius "*Cogito ergo sum*" (I think, therefore I am) with the new motto "**I fish, therefore I lie**".

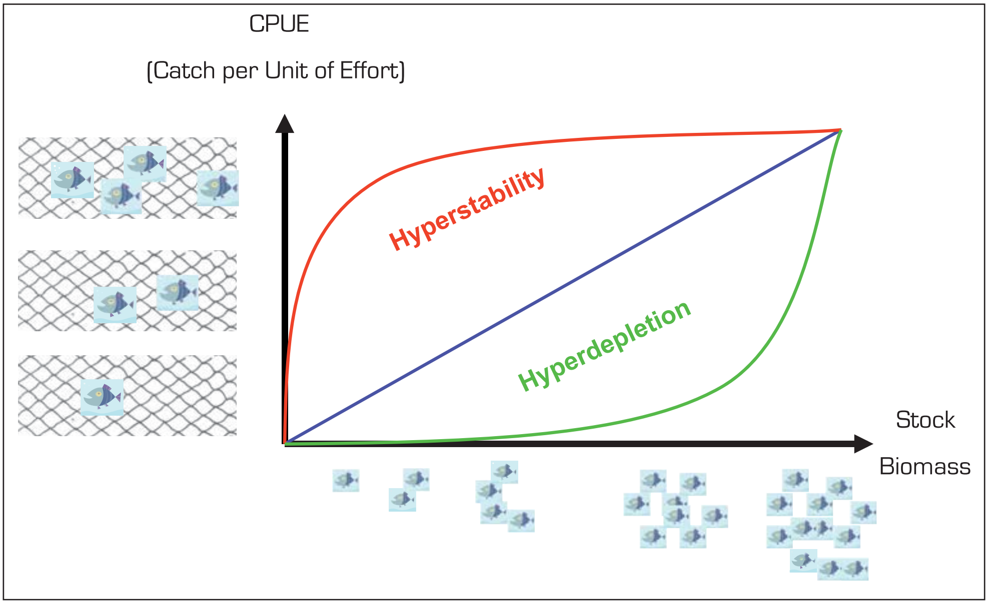


Figure 1. Theoretical relationship between stock size and CPUE experienced by fishermen. A linear decrease in stock size (black line) might not correspond to a linear decrease in CPUE. Indeed, CPUE might show hyperstability (red line; CPUE is still high although real stock size diminished) or hyper-depletion (green line; CPUE sharply decrease although only little decline in stock size is present).

pological approach and social sciences protocols. In particular, available guidelines usually rely on this background and especially on case-studies where indigenous communities (and their traditional knowledge) are the research focus. Therefore, much attention is given to create a favourable communication environment between interviewers/observers and informants, and to apply strict ethical rules, that will be later discussed in this paper. It is worth noting that this approach is valuable even in the context of "Western" fishermen, since many social dynamics are somehow similar and should contribute to prevent or minimize misreporting.
Prior to the establishment of field data collection, it is necessary to carry out some preparatory activities. In particular, it is necessary to define goals and objectives of data collection and the process to be applied, such as the timeline and the staff that will be involved in the activities. Generally, the inclusion of anthropologists/ethnobiologists (therefore the establishment of a multidisciplinary group) will ensure that both scientific and anthropological issues will be adequately addressed and balanced.
In particular, it is necessary to define some stakeholders, whose contribution is usually fundamental in order to contact the informants. Moreover, informants' features should be adequately defined prior to the research activities. For instance, a study might be based only on the collection of data from skippers and not normal fishermen, since it has been demonstrated that fishermen's experience may differ according to the role played by informants in the crew (Bunce *et al.*, 2000). Once the study area and sites have been chosen, it will be

necessary to define in details the parameters and sub-parameters, consistent with the research objectives, to be collected (e.g., what species, fishing activities, catches, etc.).

FIELD DATA COLLECTION: METHODOLOGIES

Various methods can be used for documenting LEK. Ranging over a gradient that spans from a qualitative to a quantitative approach, they include observations, oral histories, semi-structured interviews, and surveys (for a full description see the handbook "Socioeconomic manual for coral reef management" by Bunce *et al.*, 2000 and the chapter "Oral histories: a guide to its creation and use" by Fogerty, 2008). Each method will be shortly described below taking into account its requirements, approach, strengths and weaknesses.

Observations

Observations are qualitative descriptions of what the team members see and are obtained by attentively watching and recording the surroundings. This approach provides first hand insights into activities that are difficult for people to describe, in particular referring to stakeholders and their material culture.
Requirements: it needs trained researcher, camera, binoculars, and possibly a recorder.
Approach: determine useful activities to be described; walk through the area; introduce yourself; ask questions.
Strengths: this allows providing highly reliable source of information, usually those not described by stakeholders; allows assessment team to be familiar with the community and stake-holders, thus it may help in establishing good relationships.
Weaknesses: it is limited by the time of the day; it is difficult to carry out at sea; it generates data that could not be statistically analysed.

Oral histories

Oral histories are verbatim, or near verbatim, accounts of stories, anecdotes or personal biographies of informants, using their own language and terminology with the aim of generating in-depth and explanatory qualitative information on specific issues relevant for the informants; identifies local terminology, language.
Requirements: a facilitator with full understanding of local language; a tape recorder.
Approach: encourage informants to answer questions using their own words, to express opinions, experiences and memories.
Strengths: it provides in-depth qualitative information, particularly on historical events and personal memories.
Weaknesses: it can generate a large volume of extraneous data; it is time consuming both for interviewers and informants; it generates data that could not be statistically analysed.

Semi-structured interviews

Semi-structured interviews are a set of open-ended questions or discussion points intended to generate qualitative information. They provide flexibility to the interviewer to probe for answers and they generate in-depth and explanatory qualitative information on specific issues relevant for the informants.

Requirements: a facilitator; notes + tape recorder.
Approach: it is best to start with the broadest questions; probe for details; do not leave issues unanswered.
Strengths: two-way interactions; encourage informants.
Weaknesses: usually data cannot be statistically analysed.

Surveys
Surveys are usually based on highly structured, close-ended questions (e.g., multiple choices, true/false) that are used to generate quantitative data on specific topics; data can be statistically representative of the whole group of informants.
Requirements: well structured questionnaire.
Approach: to follow the questionnaire without asking questions simultaneously.
Strengths: they provide quantitative data that can be considered as representative of the whole group of informants (e.g., a fishermen community).
Weaknesses: time consuming (to reach a representative sample); discourage people to be involved in the data collection framework.

Marine ecologists have been particularly interested on the application of semi-structured interviews and surveys, since they may provide data that can be statistically analysed. In doing so, visualization techniques proved to be very effective when collecting information. They include the use of maps to visualize fishing grounds and species' distribution or habitat preferences, timelines and seasonal calendars as well as historical transects (see Bunce *et al.*, 2000, for further insights).
When creating LEK, it is necessary to define the sample size (i.e., the number of informants to be interviewed) and the sampling procedures. These issues are relevant especially when carrying out semi-structured interviews and surveys, since the number of informants should be representative of the whole group of informants in the investigated site (some practical advice on the estimation of sample size may be found in Bunce *et al.*, 2000, but see also the following paragraph "Examples from the field" for some numerical examples). The sampling strategies (i.e., selection of informants) are usually defined on the basis of the features of the investigated community, and on the aims of the research activities. A non-random sampling, or opportunistic selection of informants, is usually adopted when no particular statistical analysis is needed and, for instance, only a small group of collaborative informants is contacted. Sometimes a "snow-ball" sampling approach might be applied: this implies that, starting from a small group of informants who proved to be reliable and collaborative, other informants are identified and contacted under their suggestion. A random sampling is applied when informants are randomly chosen and contacted to carry out interviews over the total number of potential participants (e.g., skippers, fishermen). This approach might be further developed by taking into account some stratification factors (for instance considering the age distribution of informants, in order to carry out interviews on balanced groups of people belonging to different age – or experience – classes).
In practise the random approach, while statistically valid, has some drawbacks, since not all informants have the same willingness to collaborate, and thus collected data might be of lower quality when compared to those obtained from a snow-ball approach.

Guiding principles in LEK creation

Several guiding principles should be taken into account when creating LEK (Fogerty, 2008). Apart from those related to the methodology itself, the most compelling ones are those related to the relationships to be established with local communities, stakeholders and informants. It is not surprising that these principles have been established to guide the ethical aspects of the interactions between "Western researches" and local, indigenous communities. However, to our view, their value is general, and they should be also applied in the framework of researches carried out in "developed" countries. Researchers should be aware that they do need to respect stakeholders and informants community, being clear in presenting the objectives of the research and being pleasant, encouraging informants and, above all, being non-judgmental. Moreover, Fogerty (2008) remarks that each interview should be covered by a formal contract between the narrator and interviewer's institution, that describes the objectives of the research and what will be the final use of collected information; it would be necessary to provide to informants the written and recorded records of interviews. Researchers should organize meetings to communicate the general results of the research and discuss their contents with those who participated to the research and with the whole community. Indeed, Shackeroff and Campbell (2007) remarked that too often LEK has been considered as something to be "downloaded" from local communities, and not "created" as a result of a proper two-way communication; as a result, conversation become a sort of interrogation, a sort of interviewer-dominated session.

Examples from the field

We selected some case-studies as examples of applications of LEK studies in marine ecology, among the various available, with the aim of showing the potential of this approach and to provide some further insights on the methodological approaches previously described in this paper.
For instance, in the framework of the History of Marine Animal Populations (HMAP) Mediterranean and Black Sea project, our team was involved in the collection of oral histories and semi-structured interviews (still ongoing) with fishermen belonging to the port of Chioggia, the main fishing port in the Northern Adriatic Sea. A short video extract of three interviews (with English subtitles) can be seen in the HMAP web site (www.hmap-coml.org) while a more extensive video (without translation) and further interviews contents is provided with the book "*Un altro mare*" ("A different Sea"; Fortibuoni *et al.*, 2009). The interviews were set up in order to gather information of fishermen of different generations (from 40 to 84 years old) on their perception of changes in fishing catches over time. Oral history interviews, although qualitatively, confirmed the presence of the perception of very marked changes in marine biodiversity. Fishermen highlighted that many species faced a sharp reduction (or disappeared) in the last two to five decades either in the Northern Adriatic Sea and the Venice Lagoon. However, different interpretations were given to this phenomenon, including over-fishing and changes in fishing gear technology, as well as pollution, nursery habitat disruption and land use reclamation.

Notwithstanding the inherent qualitative features of the oral history survey, this activity was quite useful to obtain information on changes on fishing technology over time and on those target species that were likely to have collapsed. Thus, the value of such information is very relevant in order to guide the following development of the research when adopting a more statistically structured approach. Therefore, our advice for those interested on carrying out a LEK study, is to start with this approach, also to "tune" and increase the relational skills of the researchers involved in the team. Moreover, video interviews showed to be very effective when communicating to no-scientific audience the SBS concept, and thus to increase the public awareness on human-induced changes in marine biodiversity that is, in turn, one of the goals of the Census of Marine Life project.
A more structured approach was applied by Sàenz-Arroyo *et al.* (2005) in the framework of the study of the shifting in the environmental baselines of fishermen in the Gulf of California. The authors conducted interviews by means of semi-structured and structured questionnaires (i.e., survey) in 11 different communities. 108 fishermen were interviewed with a balanced and stratified design according to fishermen age (15-30; 31-54; >54 ys). Informants were asked to evaluate whether or not, according to their fishing experience, some selected species (populations) declined or not over time. Results revealed a rapid inter-generational shift in fishermen perception in the seascape, with older fishermen mentioning a larger number of depleted species and fishing sites over time. Moreover, a general consistency in respondents perception within class age was observed, confirming the above mentioned pattern. A further part of the research dealt with the endangered grouper *Micteroperca jordani* allowing depicting a decline in best day's catch (n. of groupers) and in the size of the largest gulf grouper ever caught with decreasing fishermen age. It is worth noting that this research provided quantitative data that were compared by means of simple statistical analysis. At the same time the coherence between data among fishermen of the same generations clearly provide the evidence of a Shift in the cognitive baseline of fishermen.
Neis and colleagues (1999) used LEK approach to describe change in species' ecology (seasonality and distribution), fishing capacity and effort, as well as CPUE cod (*Gadus morhua*) and lumpfish (*Cyclopterus lumpus*) in coastal Newfoundland. For the purpose, they used questionnaires, semi-structured interviews, visualization techniques (maps) and taxonomic interviews carrying out 56 direct interviews plus telephone follow-up. Methodological approach followed a snow-ball sampling of "expert" fishermen (skippers) applying a stratification considering fishing vessel size (< or > 35 tonnes); interviews lasted between 1.5 to 4 hours. This research showed that very detailed information in changes in fishing effort, fishing capacity and CPUE can be obtained, along with high resolution maps on species' distribution and seasonality. Moreover, a sharp reduction in CPUE was described, along with an increase in fishing capacity. It is worth noting, however, that interviews were very time intensive and, at the same time, fishery independent data were needed to provide some assumptions needed for data analysis.

The forefront of LEK research in marine sciences

The previous examples provide some evidences of the possible use of LEK in the framework of marine research. However, much research activities must be carried out to clearly define its full potentials and limitations. Indeed Papworth *et al.* (2009) highlighted that SBS has not been thoroughly investigated. For instance quoting, among others, the above mentioned paper of Sàenz-Arroyo *et al*. (2005), they showed that two different conditions are necessary to the identification of SBS: i) biological changes must be present in the system and ii) perceived changes must be consistent with the biological data. While this paper, although indirectly, challenge the use of LEK to detect SBS in areas where no biological fishery-independent data are available, there are some evidences in the literature of the presence of a good agreement between LEK and biological data. For instance, Rochet *et al*. (2008) highlighted good agreement between fishermen's perceptions and scientific data in the English Channel, showing that fishermen had also a great potential to detect early warnings of change in this ecosystem. However, according to the study of Ainsworth and Pitcher (2005) carried out in British Columbia, a more limited agreement between formal stock assessment and fishermen LEK can be expected when dealing with large number of species, although they reported that agreement increased when taking into account fishermen's experience on each single investigated stock.

Therefore the test of consistency between LEK and scientific data should deserve more attention in future research, since a larger number of studies are needed to fully understand what are the key factors (e.g., number and typology of informants) and methodological frameworks that allows LEK to be effectively informative for marine science. At the same time, other interesting researches confirmed the potential of this approach and will deserve more attention in the future. Among these, we wish to quote the studies that dealt with the identification of species' essential fish habitats (Bergmann *et al*., 2004), researches aimed at the early detection of alien fish invasions (Azzurro, 2009), the inclusion of LEK in the setting of ecological models in data poor systems (Ainsworth *et al*., 2008) as well as studies that used more sophisticated statistical approaches to study species' ecology and behaviour (Mackinson *et al*., 2001) or to analyse the inherent features of cognitive knowledge in fishermen in regards of ecosystem functioning (Özesmi and Özesmi, 2004; Prigent *et al*., 2008).

Conclusions

LEK is more than a promising tool for investigating changes in marine biodiversity and its exploitation pattern. However, this knowledge is typically "volatile", being preserved (and hidden) in human experience. Murray *et al*. (2006) showed that there is current shift from LEK towards what they called "Globalized Harvesting Knowledge" as fishermen, due to the globalization process, become increasingly more disconnected to their socio-ecological relationships associated with traditional species and stocks. This is posing an important, but exiting, challenge to all scientists involved in this research field: the urgent need on "creating" LEK before time will let it disappear and its preservation for future generations. All this should be carried out in the framework of contrasting the SBS, thus allowing present and future generations to have extensive knowledge of the past state of marine biodiversity, that in turn should contribute to provide a societal support to contrast biodiversity erosion in the world.

Acknowledgments

We gratefully thanks HMAP, CoML, Sloan Foundation, the *Regione Veneto* and the *Associazione "Tegnùe di Chioggia"* that supported our research activities on the Historical Ecology and LEK in the Northern Adriatic Sea and Venice lagoon, and those fishermen who collaborated and inspired our activities, by narrating a seascape that is, unfortunately, under profound threat.

Bibliography

AINSWORTH C.H., AND PITCHER T.J. (2005). Using Local Ecological Knowledge in ecosystem models. Fisheries Assessment and Management in Data-Limited Situations. Alaska Sea Grant College Program. AK-SG-05-02, 289-304.

AINSWORTH C.H., PITCHER T.J., AND ROTINSULU C. (2008). Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. Biological Conservation 141: 848-859. Available free at: www.reefbase.org.

AZZURRO E. (2009). Unusual occurrences of fish in the Mediterranean Sea: an insight into early detection. In Fish Invasions of the Mediterranean Sea: Change and Renewal, D. Golani & B. Applebaum-Golani (Eds.). Pensoft Publisher, Sofia-Moscow , pp. 99-126.

BERGMANN M., HINZ H., BLYTH R.E., KAISER M.J., ROGERS S.I., AND ARMSTRONG M. (2004). Using knowledge from fishers and fisheries scientists to identify possible groundfish 'Essential Fish Habitats'. Fisheries Research 66: 373–379.

BERKES F. (1993). Traditional Ecological Knowledge in perspective. In Traditional Ecological Knowledge concepts and cases, Inglis T.I. (Ed.). International Program on Traditional Ecological Knowledge, Canadian Museum of Nature, Ottawa. pp. 1-10. Available at: http://www.idrc.ca/en/ev-9321-201-1-DO_TOPIC.html.

BERKES F., COLDING C., AND FOLKE C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10(5): 1251-1262.

BOLSTER W.J. (2006). Opportunities in marine environmental history. Environmental History 11(3): 567-597.

BUNCE L., TOWNSLEY P., POMEROY R., AND POLLNAC R. (2000). Socioeconomic manual for coral reef management. IUCN, The World Conservation Union. Australian Institute of Marine Science. Townsville, Australia: NOOA. Available at: www.reefbase.org.

CARDINALE M., HAGBERG J., SVEDÄNG H., BARTOLINO V., GEDAMKE T., HJELM J., BÖRJESSON P., AND NORÉN F. (2010). Fishing through time: population dynamics of plaice (*Pleuronectes platessa*) in the Kattegat–Skagerrak over a century. Population Ecology 52: 251–262.

FOGERTY J.E. (2008). Oral history: a guide to its creation and use. In The historical ecology handbook, Egan D., Howell E.A., and Meine C. (Eds.). pp. 101-119.

FORTIBUONI T., GIOVANARDI O., AND RAICEVICH S. (2009). Un altro mare. Edited by Associazione "Tegnue di Chioggia" – onlus. 221 pp.

GARCÍA-QUIJANO C.G. (2007). Fishers' knowledge of marine species assemblages: bridging between scientific and local ecological knowledge in Southeastern Puerto Rico. American Anthropologist 109(3): 529–536.

HILBORN R., AND WALTERS C. J. (1992). Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Chapman and Hall, New York. 570 pp.

HOLM P. (2003). History of marine animal populations: a global research program of the Census of Marine Life. Oceanologica Acta 25: 207–211.

HUNTINGTON H.P. (2000). Using traditional ecological knowledge in science: methods and applications. Ecological Applications 10(5): 1270-1274.

JACKSON J.B.C., KIRBY M.X., BERGER W.H., BJORNDAL K.A., BOTSFORD L.W., BOURQUE B.J., BRADBURY R.H., COOKE R., ERLANDSON J., ESTES J.A., HUGHES T.P., KIDWELL S., LANGE C.B., LENIHAN H.S., PANDO J.M., PETERSON C.H., STENECK R.S., TEGNER M.J., AND WARNER R.R. (2001). Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530): 629-37.

JOHANNES R.E., FREEMAN M.M.R., AND HAMILTON R.J. (2000). Ignore fishers' knowledge and miss the boat. Fish and Fisheries 1: 257-271.

KUHN T.S. (1962). The structure of scientific revolutions. Chicago: University of Chicago Press.

LOTZE H.K., AND WORM B. (2009). Historical baselines for large marine animals. Trends in Ecology and Evolution 24(5): 254-262.

LOTZE H.K., LENIHAN H.S., BOURQUE B.J., BRADBURY R.H., COOKE R.G., KAY M.C., KIDWELL S.M., KIRBY M.X., PETERSON C.H., JACKSON J.B.C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312: 1806-1808.

MACKINSON S. (2001). Integrating local and scientific knowledge: an example in fisheries science. Environmental Management 27(4): 533-545.

MORENO-BÁEZ M., ORR B.J., CUDNEY-BUENO R., AND SHAW W.W. (2010). Using fishers' local knowledge to aid management at regional scales: spatial distribution of small-scale fisheries in the Northern Gulf of California, Mexico. Bulletin of Marine Science 86(2): 339-353.

MURRAY G., NEIS B., AND JOHNSEN P. (2006). Lessons learned from reconstructing interactions between local ecological knowledge, fisheries science, and fisheries management in the commercial fisheries of the Newfoundland and Labrador, Canada. Human Ecology 4: 549-571.

NEIS B., SCHNEIDER D.C., FELT L., HAEDRICH R.L., FISCHER J., AND HUTCHINGS J.A. (1999). Fisheries assessment: what can be learned from interviewing resource users? Canadian Journal of Fisheries and Aquatic Sciences 56: 1949-1963.

OMMER R.E., PERRY R.I., AND NEIS B. (2007). Bridging the gap between social and natural fisheries science: why is this necessary and how can it be done? American Fisheries Society Symposium 49: 587-595.

ÖZESMI U., AND ÖZESMI S.L. (2004). Ecological models based on people's knowledge: a multistep fuzzy cognitive mapping approach. Ecological Modelling 176: 43-64.

PANDOLFI J.M., BRADBURY R.H., SALA E., HUGHES T.P., BJORNDAL K.A., COOKE R.G., MCARDLE D., MCCLENACHAN L., NEWMAN M.J.H., PAREDES G., WARNER R.R., AND JACKSON J.B.C. (2003). Global trajectories of the long-term decline of coral reef ecosystems. Science 301(5635): 955-958.

PAPWORTH S.K., RIST J., COAD L., AND MILNER-GULLAND E.J. (2009). Evidence for shifting baseline syndrome in conservation. Conservation Letters 2: 93–100.

PAULY D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution, 10: 430.

PAULY D., AND PALOMARES M.L. (2005). Fishing down marine food web: it is far more pervasive than we thought. Bulletin of Marine Science 76(2): 197–211.

PAULY D., CHRISTENSEN V., GUÉNETTE S., PITCHER T.J., SUMAILA U.R., WALTERS C.J., WATSON R., AND ZELLER D. (2002). Towards sustainability in world fisheries. Nature 418(8): 689-695.

PITCHER T.J. (2001). Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. Ecological Applications 11(2): 601-617.

PRIGENT M., FONTANELLE G., ROCHET M.J. AND TRENKEL V.M. (2008). Using cognitive maps to investigate fishers' ecosystem objectives and knowledge. Ocean and Coastal management 51(6): 450-462.

REYES-GARCÍA V., VADEZ V., TANNER S., MCDADE T., HUANCA T., AND LEONARD W.R (2006). Evaluating indices of traditional ecological knowledge: a methodological contribution. Journal of Ethnobiology and Ethnomedicine 2: 21.

ROCHET M.J., PRIGENT M., BERTRAND A., CARPENTIER A., COPPIN F., DELPECH J.P., FONTENELLE G., FOUCHER E., MAHÉ K., ROSTIAUX E., AND TRENKEL V.M. (2008). Ecosystem trends: evidence for agreement between fishers' perceptions and scientific information. ICES Journal of Marine Science 65: 1057-1068.

ROSA I.M.L., ALVES R.R.N., BONIFÁCIO K.M., MOURÃO J.S., OSÓRIO F.M., OLIVEIRA T.P.R., AND NOTTINGHAM M.C. (2005). Fishers' knowledge and seahorse conservation in Brazil. Journal of Ethnobiology and Ethnomedicine, 1: 12.

ROSENBERG A.A., BOLSTER W.J., ALEXANDER K.E., LEAVENWORTH W.B., COOPER A.B., AND MCKENZIE M.G. (2005). The history of ocean resources: modeling cod biomass using historical records. Frontiers in Ecology and the Environment 3(2): 84-90.

SADOVY Y., AND DOMEIER M. (2005). Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. Coral reefs 24(2): 254-262.

SÀENZ-ARROYO A., ROBERTS C.M., TORRE J., CARINO-OLVERA M., AND HAWKINS J.P. (2006). The value of evidence about past abundance: marine fauna of the Gulf of California through the eyes of 16th to 19th century travellers. Fish and Fisheries 7: 128-146.

SÀENZ-ARROYO A., ROBERTS C.M.M., TORRE J., CARINO-OLVERA M., AND ENRIQUEZ-ANDRADE R.R. (2005). Rapidly shifting environmental baselines among fishers of the Gulf of California. Proceedings of the Royal Society B 272: 1957-1962.

SHACKEROFF J.M., AND CAMPBELL L.M. (2007). Traditional Ecological Knowledge in conservation research: problems and prospects for their constructive engagement. Conservation and Society 5(3): 343-360.

WATSON R., AND PAULY D. (2001). Systematic distortions in world fisheries catch trends. Nature 414: 534-536.

MEDITERRANEAN ECOSYSTEMS, SHIFTING BASELINES AND DATABASES

Konstantinos I. Stergiou
Aristotle University of Thessaloniki, School of Biology - Department of Zoology, Hellas (Greece)
e-mail: stergio@bio.auth.gr

Key-words: *Mediterranean, marine ecosystems, shifting baselines, databases, FishBase*

Fish and fishing were very important in ancient life and economy throughout the Mediterranean Sea (e.g., Curtis, 2005; Bekker-Nielsen, 2005). This becomes apparent from their wide use not only as a food source, as we all know, but also as a source of inspiration for artistic/pictorial representations (e.g., wall paintings - frescos, mosaics, sculptures, cosmetic pallets, coins) and in a variety of written accounts. In fact, fish were one of the two greatest passions of ancient Athenians (Davidson, 1997).
Some of the most famous paintings are the Minoan frescos such as the "dolphins", a fresco in queen's palace in Knossos (Greek island of Crete) (Figure 1), the "flying fish" from the bronze age excavation of Phylakopi on the Greek island Milos (http://en.wikipedia.org/wiki/Phylakopi) and the "little fisher from Thera" (see later Figure 3), from the Greek Santorini Island, Cyclades, all dated back to some 3600 years before present. Minoan artists used bright colors and detailed representations (Economidis, 2000; Sherratt, 2000; Eleftheriou, 2004), two facts allowing specialists to identify most of the animals depicted in the frescos (e.g., echinoderms, cephalopods, fishes, dolphins) at the species level (Economidis, 2000; Eleftheriou, 2004). Because of this, such frescos have, apart from their historic and artistic value, a clear ecological value (see below).

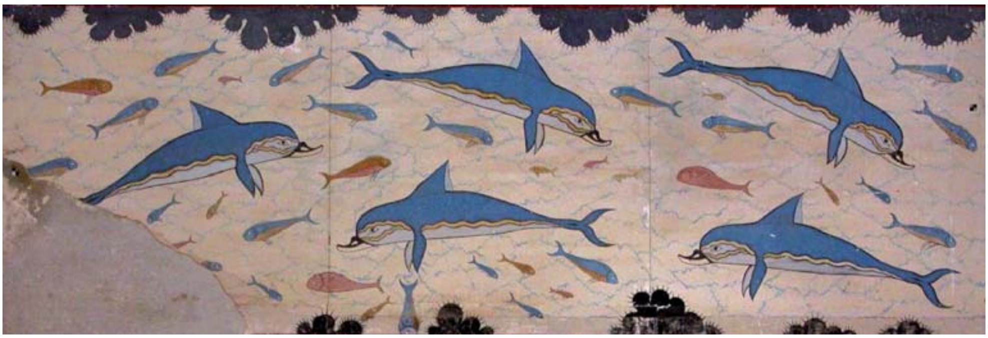


Figure 1. "This fresco depicts a Mediterranean sea about 3600 years ago teeming with life. Today, the Minoans are gone, while the sea itself has been impoverished by heavy exploitation..." [from Halley and Stergiou (2005)] (Photo provided by T. Pitcher).

The first writings on fishes can be found in the works of ancient Greeks and Latins, some more known than others. Such written sources were usually books on "natural history" or books devoted to fishes in which one can find many descriptions of various aspects of marine life and biodiversity, fishes, fishing methods, and the life of fishers. Thus, Aristotle (384-322 BC), the greatest polymath of all times, in his books on animals (History of animals) describes various aspects of the life history of fishes and other marine organisms. For instance, he was the first one to define that trophic level (which expresses the position of organisms in the food webs) of fishes increases with size (Figure 2), when writing that the big fish eat the smaller ones (Stergiou, 2005). Another example is the various observations of Aristotle on the habitat, diet, and spawning of various species such as *Mullus* spp., *Diplodus annularis*, *Gobius cobitis*, *Parablennius sanguinolentus* (Tipton, 2006; 2008). Today, these species occupy the waters of Greece as they did in Aristotle's time but most probably in smaller abundances.

Pliny the Elder (23–79 AC), a naturalist and natural philosopher during the early Roman Empire also wrote a book on natural history ("*Naturalis Historia*"). This book, which had a very strong influence in the pre-scientific period (Beagon, 2006), included information on fishes.

The Greek Oppianos of Cilicia (in the 2nd half of the 2nd century) wrote a poem on fishing called "*Halieutika*", which has received large scientific attention. In this book one can find information on the habits, habitat, breeding, feeding and parasites of fish and shellfish (Egerton, 2001). Thus, for example, when Oppianos writes that (see Egerton, 2001, p. 203): "Fishes differ in breed and habit and in their path in the sea, and not all fishes have like range. Some keep by the low shores, feeding on sand and whatever things grow in

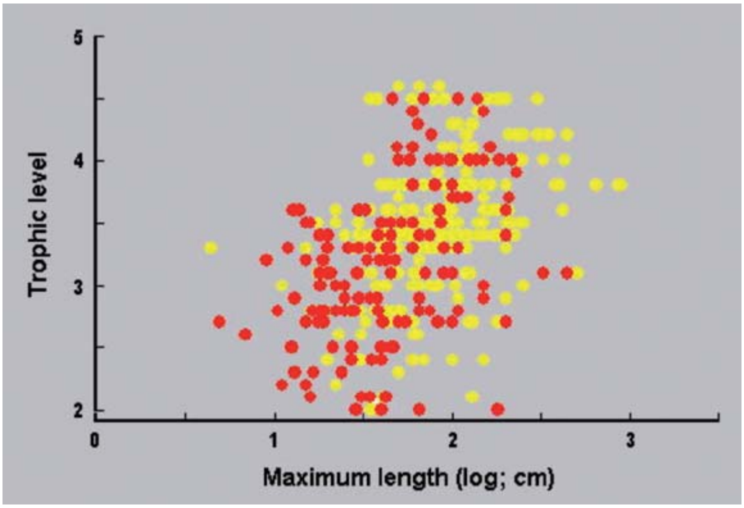


Figure 2. Relationship between maximum body length and trophic level for a variety of fish species (extracted from www.fishbase.org).

the sand... Others feed in the mud and the shallows of the sea... the terrible Stingray, red mullet, horse mackerel...", clearly provides information on the habitat and trophic level of various fish species.

Information on fishes can be also found in dedicated works of other less known writers (e.g., Archippos, 5th-4th century BC, wrote the comedy "Fishes" Dorion, 1st century BC, wrote a book "On fishes" Nouminios wrote a book on fishing called "*Halieutikos*", Euthidimos wrote "On salted"; and Antiphanes on "Fishing") (Faklaris, 1999).

Yet, information on fishes is not only found in "specialized" books of "natural history" but can be also found scattered in other written sources. For instance, information on fishes can be found in the tragedies of the Greek playwright, the father of tragedy, Aeshylos (4-5 century BC) (e.g., for tuna movements and sight) and in the book "Histories" of the Greek historian Polivios (203-120 BC) (e.g., swordfish fishery) (http://el.wikipedia.org/wiki/%CE %91%CE%BB %CE%B9%CE%B5 %CE%AF%CE%B1#cite_note-6) A very good example comes from Lucius Annaeus Seneca (known as Seneca) (3 BC – 65 AC), a Roman philosopher (and not only), who mentions a large red mullet, *Mullus barbatus*, given to Tiberius (Gummere, 1925, in Epistle XCV: from Tripton, 2008): "A mullet of monstrous size was presented to the Emperor Tiberius. They say it weighed four and one half pounds". Another good example comes from Athenaeus (2nd-3rd century AC) who in his books "The Deipnosophists" mentions that the sardine, *Sardina pilchardus*, has almost the same length with chub mackerel, *Scomber japonicus* (http://www.mirsini.gr/index.php?id=639).

Fish continued to play and still play a major role in our society. They are depicted in the works of many painters (e.g., Alexander Adriaenssen, 1587-1661; Edouard Manet, 1832-1883; Alexander Dalziel, 1781-1832; De Kiriko, 1888-1978; Tsoklis, 1930 -), in sculptures, in writing accounts (e.g., books, newspapers, fishing journals; see Stergiou 1984), movies and TV shows, and other sources. Dimitrios Moutopoulos has a huge collection of Greek movies since the late 1940s and is extracting all scenes related to fish and fishing. This will be one major contribution to the recent history of fish and fishing as depicted in the Greek cinematography.

But what is the value of such diverse information/sources in a marine ecological context? Their value can be realized within the context of the effects of fishing on marine ecosystems and the setting of baselines (see Pauly, 1995) against which such effects can be compared. Nowadays, it is generally accepted that fisheries resources are overfished and that marine ecosystems, which support such resources, are threatened. Fishing removes the large predators (e.g., Christensen *et al.*, 2003; Myers and Worm, 2003), which are generally positioned high in the food webs (Froese and Pauly, 2000; Stergiou and Karpouzi, 2002) (Figure 2). In addition, fishing has many other direct and indirect impacts on marine ecosystems both at the community level (i.e., destruction of the structure and heterogeneity of benthic habitat; change in relative abundance of species, decrease in species diversity, changes in predation/competition rates; decrease in catch variability) and life-history level (i.e., decrease in mean body size, truncated age-classes, decrease in mean size and age at maturity, changes in sex ratio, decrease in population reproductive potential, genetic diversity) all of which lead to an increase in the ecosystem production/biomass ratio and drive ecosystems immature

(Stergiou, 2002; Stergiou and Christensen, 2010). This induces ecological adaptations and evolutionary trends, and favor species that generally have short longevity, small size, small length at maturity, high growth rates and high productivity (Stergiou, 2002; Stergiou and Christensen, 2010). Indeed, the maximum size and the length at maturity of fishes declines with increasing exploitation (a process called tropicalisation: e.g., Stergiou, 2002). Thus, historical and artistic information can be used to set historical baselines against which the life history characteristics of the nowadays species can be compared.
A good example is the fresco "little fisher" from Santorini, from which one can reconstruct the length frequency of the fishes that are held by the fisher.
The length-frequency distribution of the 12 common dolphinfish, *Coryphaena hippurus*, hold by the little fisher was reconstructed and presented in Stergiou (2005). Stergiou's (2005) reconstruction was based on Economidis' assumption (2000) that "If the height of the boy is about 120 cm, then the length of the ten smaller fish varies from about 27 to 37 cm, while, of the two biggest, that in the right-hand string is about 50 cm long, and that in the left-hand string about 60 cm". However, the average height of Minoans was 1.67 cm (see Fitton, 2002) and thus the length of the fish caught most probably ranged from 42 to 89 cm and the maximum length of the fish hold by the fisher was 89 cm rather than 60 cm, assumed by Economides (2000). In addition, the mode in the length-frequency distribution was at 50-55 cm (Figure 3).

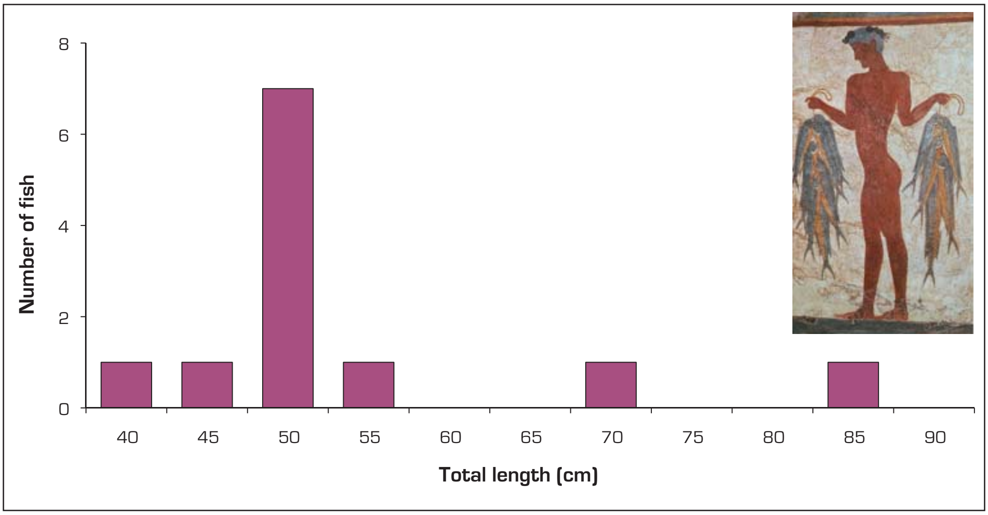


Figure 3. Length-frequency distribution of the 12 Coryphaena hippurus (common dolphinfish) that are hold by the little fisherman. Stergiou (2005) presented the length-frequency of the 12 specimens based on the assumption of Economidis (2000) "If the height of the boy is about 120 cm, then the length of the ten smaller fish varies from about 27 to 37 cm, while, of the two biggest, that in the right hand string is about 50 cm long, and that in the left hand string about 60 cm". In this graph the total length of each individual fish was reconstructed based on the assumption that the boy's height was 167 cm (the average height of Minoans: see Fitton, 2002) rather than 120 cm.

The latter seems to be much larger than the mode in the present-day length frequencies of the common dolphinfish from the Mediterranean Sea (Potoschi, 2005). Unfortunately, the small number of individuals (n = 12) in the painting could be not representative of the whole population and without a detailed knowledge of the fishing gear (that may have different selectivity) adopted for their capture, it is difficult to draw final conclusions. However, it is likely that FADs (i.e., Fish Aggregating Devices, floating systems constructed with vegetal materials) were used to catch juveniles. According to Potoschi (2005) mean and modal size of dolphinfish captured by FADs is about 40 cm (n = 310). Therefore, it seems that the modal length of the common dolphinfish in the Mediterranean has declined during the last 3600 years, most probably because of overfishing.
On a similar reasoning, Athenaus' notion, mentioned above, might be used in an ecological context. Today the maximum reported length of sardine (27.5 cm SL) is at least half that of chub mackerel (64.0 cm TL; www.fishbase.org). Given that sardine is more exploited than chub mackerel one may hypothesize that, unless ancient fishers only caught the young chub mackerels, the maximum length of sardine has drastically declined during the last 2000 years, which is not unreasonable given that (a) sardine is one of the most commercially important species in the Mediterranean being generally more intensively fished than chub mackerel and (b) sardine's length declined in the eastern Mediterranean during the late 1990 years, because of fishing (Voulgaridou and Stergiou, 2003). However, it could be also likely that the author referred to a species different than sardine, namely *Alosa fallax nilotica*, that was known as "large sardine".
Similarly, Seneca's mullet weighted approximately 1.5 kg (given that 1 Roman pound = 0.327 kg). However, nowadays the maximum weight of *Mullus barbatus (*or of *M.surmuletus*) is 1 kg (www.fishbase.gr). This also may imply a drastic decline in *Mullus* size during the last 2000 years.
Thus, all such ancient pictorial and written sources together with various archaeological findings (e.g., reconstruction of lengths or ages from skeletal remains: Zohar *et al.*, 2001) are of high scientific value for establishing historical "baselines" and reconstructing the history of marine animal populations (see Holm, 2003). However, for such diverse "seemingly irrelevant" pieces of information to be really useful, there must be an interactive dynamic framework, which will fully embody it and provide the basis for comparative analysis. In our electronic era such a framework is provided by the available online biological databases. One of the most important databases is FishBase (www.fishbase.org) for fishes. FishBase is a global information system on fishes useful for research, for education at all levels, as an information source, and for the sensitization of the public at large (Froese and Pauly, 2000; Stergiou, 2004a, b). It includes a plethora of data, covering all aspects and levels of biological organization, for the known 31400 fish species. These data are derived from more than 43700 published sources (gray literature, books, journals, symposia proceedings, reports, etc.) and 1750 collaborators. FishBase, which was developed in the late 1980s (Froese and Pauly, 2000), together with Ecopath (www.ecopath.org; Cristensen *et al.*, 2000), which was also developed during the same period, widened the scope of fisheries science. This is because these two tools in a synergetic fashion led to global studies (e.g., Pauly *et al.*, 1998; Pauly and MacLean, 2003; Froese and Binohlan, 2001; 2003; Christensen *et al.*, 2003), in which previously reported pieces of information were transformed into knowledge, thus providing the framework for answering

"mega-questions" (i.e., questions pertinent to large spatial and temporal scales, and many species; see CIESM, 2003; Stergiou, 2004a).

Historical information on maximum lengths, weight and age, species' abundances, habitats and trophic levels, and length frequencies reconstructed/decoded from frescoes, artistic representations, written sources and archaeological remains, as well as those that have been collected routinely in the last centuries, can be stored in FishBase after such information has been evaluated by experts (sociologists, historians, ecologists, taxonomists, archaeologists, painters and historians of paintings, etc.).

The same principle can be extended to other databases such as SeaLifeBase (www.sealifebase.org), which covers also non-fish marine organisms (this database covers 106500 Species, 24500 common names, 3300 Pictures, and all such information is derived from 13900 references and 150 collaborators).

The information stored in such databases can then be used to set historical baselines and identify trends in the main biological/ecological characteristics and thus to evaluate the long term effects of fishing on marine populations. Setting baselines will also allow us to approach the "Shifting baselines syndrome", firstly defined by Pauly (1995), also called the "Old timer's syndrome" which is: "... about reminding people of how things used to look, not to depress them, but to keep them from settling for a degraded world and to prevent us from some day living in visual monotony" (Randy Olson, www.shiftingbaseline.org). Having a degraded picture of the world through time will sensitize scientists, administrators and the public at large and thus will contribute to the conservation and recovery of marine populations. However, in order for such databases to accommodate such diverse information they must be continuously evolved and expanded, updated and funded.

Acknowledgments

The author wishes to thank Dr. O. Giovanardi, Dr. M. Romanelli and Prof. R. Gertwagen for their helpful comments and suggestions.

Bibliography

Bekker-Nielsen T. (2005). The technology and productivity of ancient sea fishing. In ancient fishing and fish processing in the Black Sea Region, Bekker-Nielsen T. (Ed.), Aarhus. pp. 83-96.

Christensen V., Guenette S., Heymans J.J., Walters C., Watson R., Zeller D., and Pauly D. (2003). Hundred-year decline of North Atlantic predatory fishes. Fish and Fisheries 4: 1-24.

Christensen V., Walters C.J., and Pauly D. (2000). Ecopath with Ecosim: A user's guide. Fisheries Centre, University of British Columbia, Vancouver (Canada) and ICLARM, Penang (Malaysia). 130 pp.

CIESM (2003). Mediterranean biological time series. CIESM Workshop Monograph Series 22: 1-142 (CIESM publications, Monaco, available online at www.ciesm.org/publications/split03.pdf).

Curtis R.I. (2005). Sources for production and trade of Greek and Roman processed fish. In ancient fishing and fish processing in the Black Sea Region, Bekker-Nielsen T. (Ed.), Aarhus. pp. 31-46.

Davidson J.N. (1997). Courtesans and fishcakes: the consuming passions of classical Athens. Diane Publication Co. 371 pp.

Economidis P.S. (2000). The 'little fisherman' and the fish he holds. In The wall paintings of Thera. Proceedings of the 1st International Symposium, Nomikos P.M. Conference Center, 30 August – 4 September 1997, Sherratt S. (Ed.), Athens. Volume II: pp. 555-562.

Egerton F.N. (2001). A History of the ecological sciences, Part 3. Hellenistic natural history. Bulletin of the Ecological Society of America July 2001: 201-205.

Eleftheriou A. (2004). Marine biodiversity in the Aegean Bronze Age. History of Marine Animal Populations, Mediterranean Workshop (Barcelona, Spain), September 2004 (Book of abstracts): pp. 10.

Faklaris P.B. (1999). Αι αφύαι, ο θεόπαις, λάβραξκαι ο ορφώς. Newspaper to Vima tis Kiriakis 18-7-1999.

Fitton J.L. (2002). Minoans. The British Museum Press (London).

Froese R., and Binohlan C. (2001). Empirical relationships to estimate asymptotic length, length at first maturity, and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56: 758-773.

Froese R., and Binohlan C. (2003). Simple methods to obtain preliminary growth estimates for fishes. Journal of Applied Ichthyology 19: 376-379.

Froese R., and Pauly D. (Eds.) (2000). FishBase 2000: Concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines.

Galil B.S. (2004). Of fish bones and mosaics – the fisheries of the ancient Mediterranean. History of Marine Animal Populations, Mediterranean Workshop (Barcelona, Spain), September 2004 (Book of abstracts): pp. 4-5.

Gummere R.M. (1925). Seneca. Ad lucilium epistulate morales. Vol. 3. Harvard University Press (Cambridge, Massachusetts).

Halley J.M., and Stergiou K.I. (2005). The implications of increasing variability of fish landings. Fish and Fisheries 6: 266-276.

Holm P. (2003). History of marine animal populations: a global research program of the census of marine life. Oceanologica Acta 25: 207–211.

Myers R.A., and Worm B. (2003). Rapid worldwide depletion of predatory fish communities. Nature 423: 280-283.

Pauly D. (1995). Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution 10: 430.

Pauly D., and MacLean J. (2003). In a perfect ocean – The state of Fisheries and ecosystems in the North Atlantic Ocean. Island Press (Washington). 175 pp.

Pauly D., Christensen V., Dalsgaard J., Froese R., and Jr. Torres F. (1998). Fishing down marine food webs. Science 279: 860-863.

Potoschi A. (2005). Studio sulla biologia e consistenza di popolazione di specie minori di grandi pelagici: *Seriola dumerili* Risso 1810; *Coryphaena hippurus* Linneo 1758; *Euthynnus alletteratus* Rafinesque 1810; *Sarda sarda* Bloch 1793. Mari Ionio e Tirreno meridionali. Technical Report for Ministry for Agricultural Policies, General Directory for Fishery (www.politicheagricole.it, in Italian).

Potoschi A., Cannizzaro L., Milazzo A., Scalisi M., and Bono G. (1999). Sicilian dolphin-fish (*Coriphaena hippurus* L. 1758) fishery. Scientia Marina 63(3-4): 439-445.

Sherratt S. (Ed.) (2000). The wall paintings of Thera. Proceedings of the 1st International Symposium, Nomikos P.M. Conference Center, 30 August – 4 September 1997, Athens, Volume II.

Stergiou K.I. (1984). Capelin (*Mallotus villosus*) and climatic change in the Barents Sea. MSc Thesis, Institute of Oceanography, McGill University. 242 pp.

Stergiou K.I. (2002). Overfishing, tropicalization of fish stocks, uncertainty and ecosystem management: resharpening Ocham's razor. Fisheries Research 55: 1-9.

Stergiou K.I. (2004a). The balance and conservation of the North Atlantic ecosystems? Book review of Pauly D. and J. MacLean's "In a Perfect Ocean – the State of Fisheries and ecosystems in the North Atlantic Ocean" (Island Press). Reviews in Fish Biology and Fisheries 13(4): 455-457.

Stergiou K.I. (2004b). FishBase: The Global Information System on fishes. Greek Fishing News 06/2004: 141-144.

Stergiou K.I. (2005). FishBase Symposium: Fish and More. In FishBase Symposium: Fish and More, Stergiou K.I., and Bobori D. (Eds.). Aristotle University of Thessaloniki, University Studio Press, Thessaloniki (Greece). pp. 1-4.

Stergiou K.I., and Karpouzi V.S. (2002). Feeding habits and trophic levels of Mediterranean fish. Reviews in Fish Biology and Fisheries 11: 217-254.

Stergiou K.I., and Christensen V. (2010). Fishing down food webs. In Thinking Big, Christensen V., and MacLean J. (Eds.) (In press).

Tipton J.A. (2006). Aristotle's study of the animal world: the case of the kobios and phucis. Perspectives in Biology and Medicine 49(3): 369–383.

Tipton J.A. (2008). Aristotle's observations of the foraging interactions of the red mullet (Mullidae: *Mullus* spp.) and sea bream (Sparidae: *Diplodus* spp.). Archives of Natural History 35(1): 164–171.

Voulgaridou P., and Stergiou K.I. (2003). rends in various biological parameters of the European sardine, *Sardina pilchardus* (Walbaum, 1792), in the Eastern Mediterranean Sea. Scientia Marina 67(Sup.): 269-280.

Zohar I., Dayan T., Galili E., and Spanier E. (2001). Fish processing during the early Holocene: A taphonomic case study from coastal Israel. Journal of Archaeological Science 28: 1041–1053.

HISTORICAL LOSS AND RECOVERY PROSPECTS OF MEDITERRANEAN COASTAL MARINE HABITATS

Laura Airoldi[1] and Michael W. Beck[2]
e-mail: laura.airoldi@unibo.it

Key-words: *biodiversity, coastal management, ocean history*

The following contribution is an extract from the publication: Airoldi L., and Beck M.W. (2007). Loss, status and trends for coastal marine habitats of Europe. Oceanogr. Mar. Biol. Annu. Rev. 45: 345-405.

Abstract

We have reviewed estimates of large-scale trends in the distributions and status of Mediterranean and Black sea coastal habitats. Conspicuous declines of coastal wetlands, seagrasses, biogenic reefs, and complex macroalgae have been observed in several countries. In some regions, most valuable habitats were already severely degraded or driven to virtual extinction well before 1900. Nowadays less than 15% of the coastline is considered in "good" condition. Those fragments of native habitats that remain are under threat, and most current policy and management decisions continue to lead to the functional extinction of these ecosystems. We also discuss recovery prospects for some of these habitats.

In terrestrial environments, understanding and abating the effects of habitat loss and fragmentation are a huge focus in science, conservation and management (Brooks *et al.*, 2002). Habitat loss is also well recognized as an important threat in the marine environment (Gray, 1997) but has not been as much a focus of science and conservation as in terrestrial environments (Airoldi *et al.*, 2008).
We have compiled and reviewed estimates of large-scale trends in the distribution and status of coastal habitats along European coastlines, which has included the Mediterranean and Black Sea (Airoldi and Beck, 2007). The information on coastal habitats in this region of the world is widely disparate in its availability and quality. The review focused first and foremost on information that was consistent and comparable across the whole region. This information was augmented with data from country-wide and within country

1 Dipartimento di Biologia Evoluzionistica Sperimentale and Centro Interdipartimentale di Ricerca per le Scienze Ambientali in Ravenna, University of Bologna, Ravenna (Italy)
2 The Nature Conservancy and Institute of Marine Sciences, University of California, Santa Cruz (USA)

surveys and occasionally with information from individual bays, estuaries or sections of country coastlines. The information from these finer levels of resolution mostly provided key and in depth examples of coastal change and its causes; it was not possible to collect this site-specific information for most areas. When possible information was collected from the primary literature but much of this information exists in agency reports and online databases and these were often the most common sources of information.

The data collected show that over the centuries, land reclamation, coastal development, overfishing and pollution have nearly eliminated coastal wetlands, seagrass meadows, shellfish beds, biogenic reefs and other productive and diverse coastal habitats. It is estimated that every day between 1960 and 1995, a Km of coastline was developed, with the greatest urban developments occurring along the Euro-Mediterranean coasts (EUCC - The Coastal Union, 1998). More than 50 % of the Mediterranean coasts are dominated by concrete with > 1500 km of artificial coasts, of which about 1250 km are developed for harbours and ports (EEA, 1999b). Most countries for which documentation is available have estimated losses of coastal wetlands exceeding 60% of original area, with peaks above 80 % for countries such as Italy and France (Nivet and Frazier, 2004). Documentation of seagrass loss is more limited, but there are suggestions that there may have been historical losses of *Posidonia oceanica* ranging from 40 to 80% (Meinesz *et al.*, 1991; Green and Short, 2003). Conspicuous declines, sometimes to virtual local disappearance of fucoids and other complex macroalgae have been observed along the coasts of the Mediterranean and Black Sea (Munda 1993; Benedetti-Cecchi *et al.,* 2001; Thibaut *et al.,* 2005).

A few dominant threats have led to these losses over time (Airoldi and Beck, 2007). The greatest impacts to wetlands have consistently been land claim and coastal development. The greatest impacts to seagrasses and macroalgae are presently associated with degraded water quality while in the past there have been more effects from destructive fishing and diseases. Coastal development remains an important threat to seagrasses. For biogenic habitats, some of the greatest impacts have been from destructive fishing and over- exploitation with additional impacts of disease, particularly to native oysters. Coastal development and defence have had the greatest known impacts on soft sediment habitats with a high likelihood that trawling has affected vast areas.

The concept of "shifting baselines", which has been applied mostly to the inadequate historical perspective of fishery losses, is extremely relevant for habitat loss more generally. Most habitat loss estimates refer to a relatively short time span primarily within the last century. However, in some regions, most estuarine and nearshore coastal habitats were already severely degraded or driven to virtual extinction well before 1900 (Lotze *et al.*, 2006). Native oyster reefs were ecologically extinct by the 1950s along many coastlines and in many bays well before that. These shellfish reefs are one of the most endangered coastal habitats, but some of the least protection is being directed at them (Beck *et al.,* submitted). However, there are many reasonable actions to reverse this decline and revitalize these habitats that could work across local to regional to global scales. These include improving protection; restoring systems and services; fishing sustainably; stopping the spread of non-natives; and capitalizing on joint interests in conservation, management and business to enhance and provide a focus for improving estuarine condition (Beck *et al.*, submitted).

Nowadays less than 15% of the European coastline is considered in "good" condition (EEA, 1999a), with the Mediterranean coastlines among the most severely depleted. Those fragments of native habitats that remain are under continued threat, and their management is not generally informed by adequate knowledge of their distribution and status. There are many policies and directives aimed at reducing and reversing these losses but their overall positive benefits have been low. Further neglecting this long history of habitat loss and transformation may ultimately compromise the successful management and future sustainability of those few fragments of native and semi-native coastal habitats that remain in the Mediterranean and Black Sea.

Bibliography

Airoldi L., and Beck M.W. (2007). Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology: an Annual Review 45: 345-405.

Airoldi L., Balata D., and Beck M.W. (2008). The Gray Zone: Relationships between habitat loss and marine diversity and their applications in conservation. Journal of Experimental Marine Biology and Ecology 366: 8-15.

Beck M.W., Brumbaugh R., Airoldi L., Carranza A., Coen L., Crawford C., Defeo O., Edgar G., Hancock B., Kay M., Lenihan H., Luckenbach M., Toropova C., and Zhang G. Shellfish reefs at risk globally and recommendations for ecosystem revitalization. Submitted to Bioscience.

Benedetti-Cecchi L., Pannacciulli F., Bulleri F., Moschella P.S., Airoldi L., Relini G., and Cinelli F. (2001). Predicting the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. Marine Ecology Progress Series 214: 137-150.

Brooks T.M., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A.B., Rylands A.B., Konstant W.R., Flick P., Pilgrim J., Oldfield S., Magin G., and Hilton-Taylors C. (2002). Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16: 909-923.

EEA (1999a). Coastal and marine zones. Chapter 3.14. Environment in the European Union at the Turn of the Century. State of Environment report No 1/1999. Copenhagen: EEA. Online. Available HTTP: http://reports.eea.eu.int/92-9157-202-0/en (accessed 4 August 2006).

EEA (1999b). State and Pressures of the Marine and Coastal Mediterranean Environment. Environmental Issues Series 5. Luxenbourg: OPOCE. Online. Available HTTP: http://reports.eea.europa.eu/ENVSERIES05/en/envissue05.pdf (accessed 4 August 2006).

EUCC - The Coastal Union (1998). *Posidonia* beds. In Facts & Figures on Europe's Biodiversity: State and Trends 1998-1999, Delbaere B. (Ed.), Technical Report Series, Tilburg: ECNC. Online. Available HTTP: http://www.coastalguide.org/dune/posidi.html (accessed 7 August 2006).

Gray J.S. (1997). Marine biodiversity: patterns, threats and conservation needs. Biodiversity and Conservation 6: 153-175.

Green E.P., and Short F.T. (2003). World Atlas of Seagrasses. Berkeley: UNEP-WCMC, University of California Press.

Lotze H.K., Lenihan H.S., Bourque B.J., Bradbury R.H., Cooke R.G., Kay M.C., Kidwell S.M., Kirby M.X., Peterson C.H., and Jackson J.B.C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312: 1806-1809.

Meinesz A., Lefevre J.R., and Astier J.M. (1991). Impact of coastal development on the infralittoral zone along the south eastern Mediterranean shore of continental France. Marine Pollution Bulletin 23: 343-347.

Munda I.M. (1993). Changes and degradation of seaweed stands in the Northern Adriatic. Hydrobiologia 260/261: 239-253.

Nivet C., and Frazier S. (2004). A Review of European Wetland Inventory Information. Almere: RIZA, Evers Litho en Druk.

Thibaut T., Pinedo S., Torras X., and Ballesteros E. (2005). Long-term decline of the populations of Fucales (*Cystoseira* spp. and *Sargassum* spp.) in the Alberes coast (France, North-western Mediterranean). Marine Pollution Bulletin 50: 1472-1489.

POTENTIALITIES AND CRITICALITIES OF NUMERICAL APPROACHES TO THE RECONSTRUCTION AND UNDERSTANDING OF PAST DYNAMIC OF MEDITERRANEAN SEA BIOGEOCHEMISTRY

Cosimo Solidoro, Paolo Lazzari, Simone Libralato
OGS - National Institute of Oceanography and Experimental Geophysics, Trieste (Italy)

Key-words: *model, Mediterranean, biogeochemistry, BFM, past ecosystem*

Abstract

Numerical models can contribute to reconstruct and understand present, past and future dynamics of ecosystems. However, their use is heavily constrained by the availability of information used to parameterize the interactions between the modeled system and the (non-modeled) environment surrounding such system. These interactions are technically defined as the boundary conditions which constrain model dynamics.
Here we introduce basic definitions useful to understand what a model is, and which kind of output it can provide. We will focus, as an example, on biogeochemical models, i.e. model of nutrients cycles through dissolved and particulate matter in sea water column, including living planktonic organisms. The example is used to exemplify potentialities, requirements and limitations of numerical approaches. In particular we will highlight the need of information external to the model on both marine ecosystem components (such as nitrogen concentration or density of marine population), and on environmental forcing factors (e.g., air temperature, irradiance, input from rivers). The former kind of data is needed to calibrate model parameters and assess model descriptive capabilities. The latter is used to actually produce model predictions. When considering model reconstruction of past dynamic, this external - but crucial - information might be archived, or hidden, in historical documents and sources that are not readily accessible to a traditional natural scientist, but might be retrieved by cooperation between researchers in Humanities and ecological disciplines.

Introduction

A model is an ideal representation of selected aspects of a piece of reality. It provides a theoretical framework in which to collate, integrate and reconcile in a coherent picture the phenomenological information gathered on a specific issue. As such, it is a fundamental step of cognitive processes. A model also provides a way to make predictions about the dynamic of a system under different, alternative, scenarios of external forcings, of past or present conditions under observed combinations of external forcing. In this context, predictions can be considered as the ultimate step of comprehension of the dynamics of a system.

Central to the definition of a model is the definition of the system to be modeled, that is the piece of reality we are interested in. This includes the definition of model purpose - which properties the model is built to reproduce - the definition of the spatial and time scale the model has to address, the parameters and the relationships among parameters which need to be considered, the spatial and time scale that a model need to resolve in order to properly address those relationships (level of details), geographical boundaries. This also implies the definition of which components of the system are not considered in the model (approximation adopted) and of those which are not in the system at all, but out of it. Factors external to the system are finally divided in not relevant ones, and therefore disregarded, or able to influence the dynamic of some system components. In the latter case, they are considered external forcings, or boundary conditions, and the relationships between the system and its surroundings must be parameterized.

From the above it should be clear that there is no model fit for all problems, and rather different models are (or should be) used for different purposes. Conversely there might - and generally will - be different models not only when focusing on - say - fishes rather than nitrogen, but also when focusing on nitrogen dynamics on different space (cm vs. km) or time (days vs. years) scales. Similarly, a model built for management purposes will probably be different from a model built for ranking relative effects of multiple forcings on a given output.

The first step in model construction is the choice of state variables, the set of parameters which completely describes the state of the system and its dynamic. The identification of causal relationships between state variables, which originate the changes in time of state variables, is worked out concurrently. This phase is equivalent to the identification of a conceptual model, or conceptual scheme, of a process, and it is sometime performed by using “box and arrows” parameterization (Figure 1). The conceptual scheme also elucidates how external forcings influence system dynamic.

As an example, if one is interested in “eutrophication” issues, defined as the increase in a water body productivity and organic material because of an increment of external input of fertilizers, the system will be the water body. Its state will be described by the concentration of the substances that we consider to be the most relevant fertilizers (usually nitrogen and/or phosphorus in their dissolved inorganic forms), photosynthetic organisms able to build up organic material, usually plankton and macrophytes, possibly an herbivore grazing on photosynthetic organism and a carnivore preying on herbivores. Then there might be a “box” for detritus, which accounts for dead organic material, excretion and other kind of nonliving organic particulate matter, and possibly surface sediment, where sunken detritus accumulates. Out of the system but crucial for system dynamic, there will be solar irradiance, providing the flux of photons which sustains photosynthetic activity, meteorological parameters which determine water temperature, and external input of fertilizers. Time course of these parameters are totally independent from system dynamics, so that they can be safely excluded by the definition of the system, but must be considered - and prescribed - as external forcings.

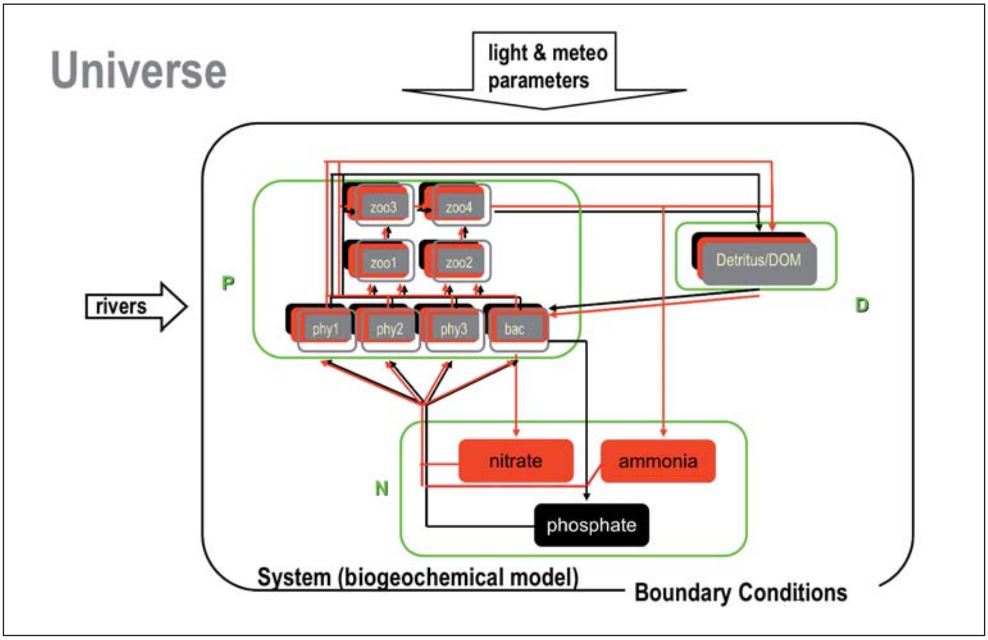


Figure 1. Scheme of a model including the biogeochemical module and the environmental forcings (i.e., light, meteorological parameters and rivers). Two cycles of matter transformation are included for Nitrogen (red) and Phosphorus (black). Arrows indicate flux of matter. The cycling phase is grouped in three green boxes: Nutrient (N), plankton (P) and residual organic matter (D). In the plankton box are included the phytoplankton (phy), zooplankters (zoo) and bacteria (bac). DOM = Dissolved Organic Matter.

It is here worth to stress that if one were interested in climate, rather than in eutrophication, the system to be considered would probably be larger and include both the water body and the atmosphere above it, and in such a case meteorological parameters would no longer be external forcings but state variables of the model.
It might also be noted that in our first approximation of an eutrophication model fishes are not considered, along with differences between different species of phytoplankton and zooplankton. This is not meant to say they are not part of the reality, and even less that the study of taxonomy is not an important part of science. On the contrary, every conceptualization of reality cannot start from but a description of species actually present in a system and their physiology. But - being it a conceptualization - a reductionistic sectorial approach including all details on all species is not pursuable, and a holistic and systemic approach must be followed, in which only a selection of aspects about a selection of players is retained, assuming they capture the essential features of the system one want to represent, given the goal and the approximation level previously defined. A model cannot be as complex as reality, and components, aspects, processes which are considered to be not relevant for the stated model goal and at the selected space-time scale, are disregarded. In this way it is possible to focus on relationships between components

which are "core" to a given issue, and pursue a systemic, rather than reductionistic, perspective. Models, like art, are lies which helps to understand the true.
A conceptual model is, per se, a precious achievement, and the base of any modeling activity. However, without a quantification of kinetic laws describing fluxes (arrows) between state variables (boxes), the possibility to fully understand all aspects of system functioning is limited. As an example, in many seas jellyfishes are increasingly more common and fishes less abundant. To model this, the first phase is to draw a conceptual scheme in which jellyfish and fishes compete for a common resource but are differentially fished by men.
A quantitative definition of the kinetics of this processes is essential. Otherwise it is difficult to understand the underlying dynamics, in fact two opposite processes are possible. Jellyfishes entered in a system after fishes were largely removed by a too massive fishing activity, and then become an extra obstacle to fish stocks repopulation even if fishing pressure has slowed down, or jellyfishes entered a non-overfished system, outcompeted fishes, and in turn caused a decline of fish stocks and fishery activity. The evaluation of contrasting, synergistic, indirect effects requires the capabilities to weight different processes, i.e. a quantitative knowledge of the system dynamic.
Translating the conceptual scheme into mathematical/numerical relationships means to build a numerical model. This can be used for prediction and understanding, including analysis of present, past, and possible future states and functioning of a marine ecosystem.

Biogeochemical modelling

Marine "ecological" models typically focus on the dynamics of biogeochemical properties, and describe cycles of major chemical elements such as nitrogen, phosphorus, carbon through dissolved and particulate matter in sea water column, including living planktonic organisms and bacteria mineralizing activity. Traditionally stemming from very simplified model developed for "water quality" – in practice dispersion and fate of a oxygen-consuming bio-degradable substance (Streeter and Phelps, 1925), nutrients cycles (Riley, 1965), and population dynamics (Lotka, 1925; Volterra, 1926), biogeochemical models took advantage of increasing availability of computational power and now describe the evolution in time of three dimensional space distributions of several ecosystem components. Higher trophic level animals, such as fish, are usually not included in these models, since their population dynamics typically require focusing over a different space-time scale, and because over the scale typically considered in biogeochemical simulation their effects can be approximated in constant terms, such as an extra-mortality of zooplankton, and an extra input of detritus. Very recently, however, several attempts have been performed to include also fish population dynamic into biogeochemical model, so achieving the modeling of the full ecosystem. Plankton productivity, anyway, is the base of the marine food web, and can therefore be regarded as a proxy of potential productivity of a sea.
Biogeochemical processes are highly depending on the physical dynamics of the sea. As an example microorganisms and nutrients are transported by currents both horizontally and along the vertical, and in doing so experience different optical and thermal conditions. Thus biogeochemical models require the three-dimensional description of principal phys-

ical processes, like mixing processes along the water column driven by seasonal changes in meteorological parameters, horizontal currents, 3D thermo-aline cells.

The Mediterranean Biogeochemical modelling: from the present to the past

The state of the art biogeochemical model for the Mediterranean basin is the OPATM-BFM model (Lazzari *et al.*, 2010), developed in the last 15 years thanks to a number of EU projects (Crise *et al.*, 1999; Crispi *et al.*, 2001; Lazzari *et al.*, 2010). It is a three-dimensional numerical model that reproduces the spatial variability of specific biogeochemical variables with around 12 km horizontal resolution and daily temporal frequency.
The model describes biogeochemical dynamic by simulating causal relationships among major elements (nitrogen, phosphorus, carbon and silica), 3 groups of phytoplankton producers, 3 herbivores and 1 carnivores zooplankton groups, detritus, 3 type of dissolved organic matter (labile, semilabile, refractory), mineralizing heterotrophic pelagic bacteria. Input data required for a simulation are the time-space distribution of solar irradiance at the sea level, evaporation fluxes, wind at the sea surface, as well as the inorganic nutrients inputs from rivers (phosphates, nitrates, silicates). All those data must be realistic to produce meaningful results. For example, when simulating recent past situations, the atmospheric data can be obtained by satellite observation (ECMWF, http://www.ecmwf.int/). The atmospheric signal is fundamental because it modulates the characteristic of the water column (mixed or stratified) with the seasonal cycling of primary producer and of organic matter deposition on the sea bottom. Additionally, distributions of nutrients over space and time are needed, in order to evaluate the dynamics of the system over time and - even more importantly - to define model initial conditions. In fact, even if a model describes how a system changes, the starting point of the simulation has to be defined in advance and externally to model dynamic. In the case of recent past model simulation, the inorganic nutrient distributions are obtained as a synthesis of in-situ measurements performed over the last past decades by experimental cruises (available in public data-set such as the MEDAR MEDATLAS database).
A comparison with observations shows that the capability of this model to describe current biogeochemical dynamic on a seasonal scale and at the Mediterranean Basin level is pretty satisfactory (Lazzari *et al.*, 2010). However, we have to stress here that this greatly benefits from the availability of good quality input data used to force model simulations.
In principle, the same, or a similar, model could be used also for reconstructing seasonal evolution of biogeochemical properties in the past, assuming - as it is possible - that there was no major changes in major biogeochemical kinetics. However - as in the present situation case, boundary conditions are required. Atmospheric distribution forcing might be derived from an analysis of atmospheric models developed to reconstruct past climate conditions. For the Mediterranean area, Trouet *et al.* (2009) reconstructed both temperature and precipitation patterns from the year 1100 to year 2000. More challenging is to obtain information on nutrients or microorganisms, representing the biogeochemical condition of large portions of the Mediterranean Sea. In fact, the Mediterranean Basin responds to a given stationary situation of boundary conditions (rivers input, atmospheric deposition, and exchanges at Gibraltar strait) by reaching a stationary spatial distribution

of nutrients in a time scale of the order of 100 years. Therefore, if we consider a simulation set in remote periods, the nutrient distributions could be very different from the present one, depending on boundary conditions in that period, and the identification of initial conditions consistent with that dynamic is far from trivial. One might disregard uncertainty in initial conditions by starting from arbitrary conditions and running a simulation long enough to reach a steady state condition, which does not depend on initial conditions. Still the boundary conditions must be reconstructed. A possible solution is to reconstruct rivers and continental inputs relying on land use of rivers drainage basins (agriculture practices, fertilizers usage, number of habitants, number of animals…), a technique sometime used also for present day estimates. It is evident however that to this purpose one needs to characterize from a geographical, social and economical perspective the societies of the past, and this requires knowledge and expertise that normally are not available to the natural scientist.

Conclusions

History, anthropology, geography, economy and many other human disciplines can offer a substantial - and impossible to substitute - contribution to the reconstruction of states and dynamic of important components of past ecosystems. These pieces of information could be used, together with information coming from natural disciplines - such as paleoecology or sedimentology - and climatological studies to force biogeochemical models, in order to represent past system dynamics. The assumption that biogeochemical kinetic laws are no different from present one, which implies the absence of adaptation of living organism to changing environment, can be maintained as a first approximation, as it is usually done in projection of ecosystem response to future climate. Conversely, the occurrence of some adaptation/evolution mechanism could be envisaged and implemented, if required, again using methodology and techniques developed for modelling future conditions (Solidoro *et al.*, 2010). Biogeochemical simulation can then provide insights and suggestion on likely seasonal dynamic of nutrients and plankton concentration occurring in the past, useful to speculate on past productivity and habitats properties of the sea.

Bibliography

Crise A., Allen J.I., Baretta J., Crispi G., Mosetti R., and Solidoro C. (1999). The Mediterranean pelagic ecosystem response to physical forcing. Progress in Oceanography 44: 219-243.

Crispi G., Mosetti R., Solidoro C., and Crise A. (2001). Nutrient cycling in Mediterranean basins: the role of the biological pump in the trophic regime. Ecological Modelling 138: 101-114.

Lazzari P., Teruzzi A., Salon S., Campagna S., Calonaci C., Colella S., Tonani M., and Crise A. (2010). Pre-operational short-term forecasts for the Mediterranean Sea biogeochemistry. Ocean Science: 6(1): 25:39.

SOLIDORO C., COSSARINI G., LIBRALATO S., AND SALON S. (2010). Remarks on the redefinition of system boundaries and model parameterization for downscaling experiments. Progress in Oceanography 84: 134–137.

LOTKA A.J. (1925). Elements of physical biology. Williams & Wilkins Co (Baltimore). 495 pp.

RILEY G.A. (1965). A mathematical model of regional variation in plankton. Limnology and Oceanography Vol. 10, Supplement: Alfred C. Redfield 75th Anniversary Volume 202-215.

STREETER W.H., AND PHELPS E.B. (1925). A study of the pollution and natural purification of the Ohio River, Public Health Bull. 146, U.S. Public Health Service, Washington D.C.Riley, 1954.

TROUET V., ESPER J., GRAHAM N.E., BAKER A., SCORSE J.D., AND FRANK D.C. (2009). Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly. Science 324: 78-80.

VOLTERRA V. (1926). Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. Atti dell'Accademia Nazionale dei Lincei 6(2): 31-113.

FROM THE GLOBAL TO THE REGIONAL WARMING: THE MEDITERRANEAN CASE FROM OBSERVATIONS OF THE LAST CENTURIES

Vincenzo Artale[1], Salvatore Marullo[1], Rosalia Santoleri[2]
e-mail: vincenzo.artale@enea.it

Key-words: *ocean circulation, Mediterranean climate, AMO, thermohaline circulation*

Abstract

The Mediterranean Sea for its own characteristic can be considered as a hot spot basin. Experimental data spanning several decades show that the circulation of the Mediterranean Sea and the processes of water mass formation that it hosts are subject to pronounced variability and change. The Eastern Mediterranean Transient (EMT), which was detected in the 90s, constitutes a direct observational evidence of such variability. From *in-situ* data provided by the MEDAR/MEDATLAS database trends in the interior of the basin as in the Mediterranean outflow in the Gulf of Cadiz were observed. Recent data analysis within the Strait of Gibraltar and in particular at Camarinal Sill South, point out an anomalous warming and salinification from the early 2000s to today, corresponding to ~0.3°C and to ~0.06 respectively. However, during the twentieth century also the Mediterranean basin has warmed quite significantly in the deep waters as well as in the surface layer. We also discuss the annual Sea Surface Temperature Anomaly (SSTA) during the last 150 years that can be estimated using several datasets. An important characteristic of this mode of SST variability is that the SST anomalies have the same sign across the entire North Atlantic and resemble the Atlantic Multidecadal Oscillation (AMO). As a future follow-up of these studies the role of the Mediterranean Sea on nearby and remote regions will be investigated in the context of present and future climate.

Introduction: the physical mechanism of the Mediterranean circulation

The Mediterranean Sea is a mid-latitude marginal sea with a maximum depth of over 4000 m (e.g., the Ionian sub-basin) and a limited exchange with the global ocean. The Mediterranean Sea is also a semi-enclosed ocean basin where a wide range of oceanic physical

1 Italian National agency for new technologies, Energy and sustainable economic development (Enea), Casaccia, Roma (Italy).
2 Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Counci (CNR), Rome (Italy).

and biogeochemical processes of global interest occur. The only two small opening are one at the Bosporus in Turkey, that connects the Mediterranean with the Black Sea, and the second one is located at the Straits of Gibraltar that connect it with the North Atlantic. The limited flows mean that water masses in the Mediterranean are exchanged only once every 80-120 years, depending from the various components of the Mediterranean hydrological cycle, but much less of the mean renewal time of the world ocean, whose order of magnitude is thousand of years. Everything that flows into the Mediterranean, *via* the major river drainage, small creeks, or even as run-off, thus resides in the Basin for decades. With the 21 countries that surround the Mediterranean supporting more than 100 million people in near shore coastal areas, and with large-scale industries lining its ports and watersheds, land-based sources of pollutants are rampant. Add to this the marine pollution generated from the region's massive shipping industry, as well as the spread of invasive species that has wreaked havoc in some Mediterranean environments, and it is easy to understand why the Mediterranean is one of the world's most polluted seas and vulnerable to climate change, in several paper is defined as a Hot-Spot (Giorgi, 2006). The Mediterranean Sea is composed of two basins of similar size, the Western and the Eastern Mediterranean Seas, separated by the shallow and narrow Strait of Sicily (Figure 1). The Strait and the Channel of Sicily plays an important role for the exchange of water masses and their physical-biogeochemical properties between the eastern and western sub-basins. The hydrological status of the channel is characterised by the Modified Atlantic Water (MAW in the following) in the surface layers (0–100 m), identified by the salinity minimum always

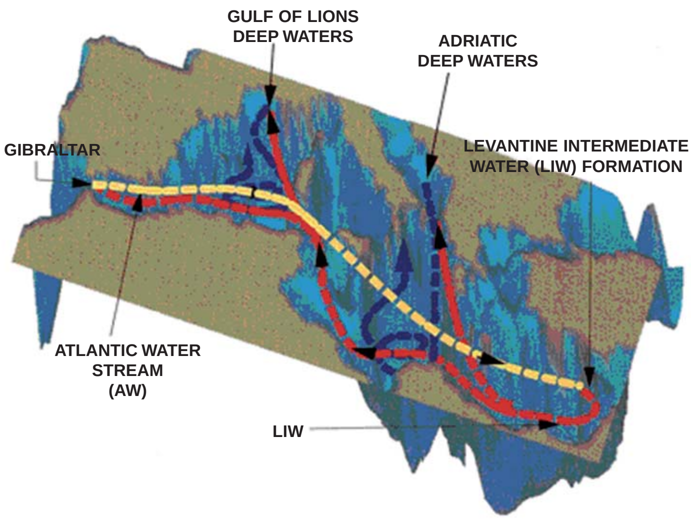


Figure 1. The main branches of the Mediterranean circulation: in yellow the incoming Atlantic water, Modified Atlantic Water (MAW), the source water of the Mediterranean circulation, in red the intermediate water originated in the Rhodes gyres and along the Turkey's coast and finally in blue the trajectory of the deep water generated in the Gulf of Lyon and in the south Adriatic. These trajectories represent together the main paths of the Mediterranean thermohaline circulation (Figure from N. Pinardi, E. Masetti, 2000).

present along the meandering jet entering from the West and stretching toward the Ionian Sea forming the Atlantic Ionian Stream (AIS). The deeper layers are occupied by the Levantine Intermediate Water (LIW) (at depth >250 m) identified by the salinity maximum, a clear signal throughout the year, considered to be a constant feature of the hydrological structure of the channel (Napolitano *et al.*, 2003). Another crucial limiting factor of the Mediterranean circulation is the Strait of Gibraltar, where the fresher Atlantic surface water flows into the basin, replacing both the evaporated water and the denser and saltier Mediterranean water flowing out into the Atlantic. The incoming Atlantic water layer is 100-200 m thick and flows eastward changing progressively its hydrological properties becoming warmer and saltier due to the air sea interaction and mixing with the saltier surface MAW. In the Levantine Basin, the LIW of relatively high temperature and salinity is formed during winter. This water mass circulates through both the eastern and western Mediterranean basin in a generally cyclonic fashion, mixes with other water mass and finally reaches the Atlantic Ocean through the Strait of Gibraltar. The LIW is usually observed between 200 and 800 m of depth. Deep water is produced at different locations in the Mediterranean Sea: in the Gulf of Lyon (western Mediterranean), in the South Adriatic, in the northeast Levantine basin and in the Aegean Sea (Roether *et al.*, 1996) where, in the '90s, was observed an anomalous production of deep water (Eastern Mediterranean Transient). Progress in the knowledge of the Mediterranean Sea circulation comes both from recent observational programs and modelling efforts. The basin's circulation is characterised by the presence of sub-basin gyres, intense mesoscale variability and a strong seasonal signal. Interannual variability is also observed, mostly related to interannual variability of atmospheric forcing. The observational picture of the western basin's general circulation can be found in Send *et al.* (1999) and its eastern counterpart in POEM Group (1992) and Malanotte-Rizzoli *et al.* (1999). A number of numerical studies on the general circulation of the basin have been realised. The results of regional numerical models of Roussenov *et al.* (2005) and Artale *et al.* (2002) show some agreement between model simulations and known features of the basin's general circulation. More recently a number of regional climate model (RCM) systems, related to the Mediterranean region, have been developed in the last two decades in order to downscale the output from large scale global climate model simulations and produce fine scale regional climate change information useful for impact assessment and adaptation studies (Artale *et al.*, 2009).

Relevance of the Mediterranean Overflow Water (MOW) for the global ocean circulation

Within the present climate, the Mediterranean Sea produces dense, warm and salty water that outflows through the Gibraltar Strait into the North Atlantic. The outflow amounts to about 1 Sv of water that can be over 5°C warmer than any other water mass in the North Atlantic at the same latitude and depth, and more than 1 psu saltier. After mixing with the surrounding water masses, the Mediterranean Outflow Water (MOW) is neutrally buoyant at about 1.000 m depth (Reid, 1979).
The spreading of the salinity anomaly associated with the presence of MOW has captured much attention in the past, and yet, major uncertainties remain. A contribution to the av-

erage salinity of the world ocean equivalent to that of MOW would be achieved by distributing over the North Atlantic the net evaporation observed over the Mediterranean Sea. The present estimate of the freshwater budget of the North Atlantic is rather uncertain, ranging from 0.2 to 0.8 Sv of net loss, north of 30° S. The corresponding estimate of the Mediterranean Water deficit ranges from 378 to 950 mm y^{-1} and therefore this also has a large error bar (Mariotti *et al.*, 2002). Assuming an area for the Mediterranean Sea of 2.5 10^{12} m^2 these values correspond to 0.03–0.08 Sv net evaporation. Therefore, the contribution of the Mediterranean Outflow to the freshwater budget of the North Atlantic can be currently estimated between 4 and 40%. Such a large uncertainty is quite impressive. It means that we are missing a fundamental quantitative detail concerning one of the important features of the climate system that is the freshwater budget of the North Atlantic (Rahmstorf, 1996).

In the broad sense discussed above, the North Atlantic plus the Mediterranean Sea can be viewed as a unique system whose "internal" dynamics, regulated by the exchanges at the Strait of Gibraltar, is still rather unknown. Artale *et al.* (2002) and Calmanti *et al.* (2006) using results from a hierarchy of numerical ocean models, study the spreading of MOW in the North Atlantic and its possible relation to the variability of the Meridional Overturning Circulation of the global ocean and in particular of the North Atlantic.

Change, trend and variability of the Mediterranean water masses

Trend and variability of the Mediterranean SST in the last 150 year

In this section, we analyse the long time SST dataset of the Mediterranean Sea. The annual Sea Surface Temperature Anomaly (SSTA) during the last 100-150 years can be estimated using several datasets (Figure 2). Among several, the Extended Reconstructed SST (ERSST.v3) dataset: 1854-present (a monthly, 2 deg resolution time series) and Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST) 1870-present (a monthly, 1 deg resolution time series) are the more extensively used (Rayner *et al.*, 2003).

The analysis of the Mediterranean SST records shows the occurrence of two evident nearly 70 years cycles during the last 150 years. These two cycles are the result of a sequence of warm and cold phases: a warm phase (positive anomalies respect to the 1971-2000 average) occurred during 1860-1880, 1925-1970 and 1985-today and the cold phase occurred during 1880-1925, 1970-1985 and presumably before 1860. The period of the observed Mediterranean multidecadal oscillation coincides with that of the well-known Atlantic Multidecadal Oscillation (AMO). The AMO index was defined, for the first time, by Enfield *et al.* (2001), as the detrended SST anomalies averaged over the North Atlantic from 0-70°N. During recent years, the Atlantic Multidecadal Oscillation has been the object of increasing interest due to its relation with arctic air-sea-ice interaction processes, the internal variability of the thermohaline circulation (THC) and to the intrinsic nonlinear behavior of the climate system.

The presence of some significant harmonic phase-coherent oscillation or amplitude and phase modulated signal in the Mediterranean time series have been investigated using harmonic F-test and spectral analysis. A significant 73 years peak, referred to AMO, that satisfy the harmonic detection test at the 99% level was found, although the correspon-

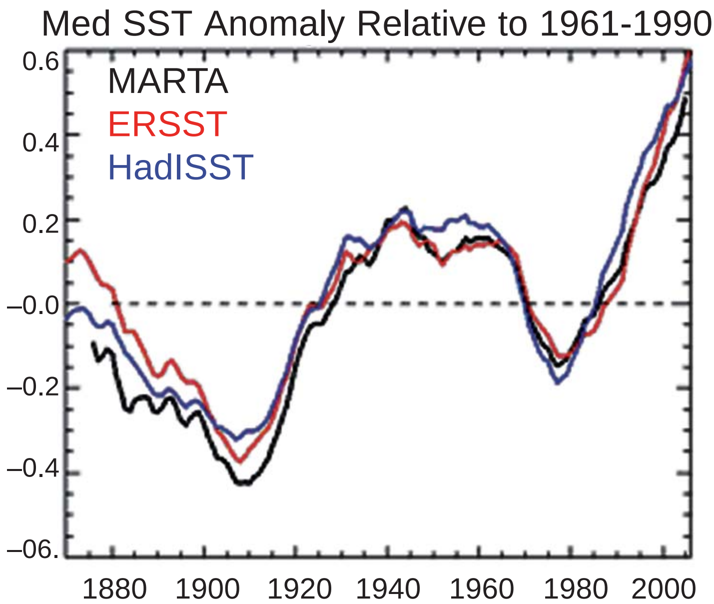


Figure 2. Behavior of the Mediterranean SST from 1854-today, elaborated from three different datasets (Marullo et al., 2009).

ding spectrum suggests the presence of a significant broad band rather that a spectral line. The actual length of the available SST time series do not permit to answer to the question whether this Mediterranean AMO signal corresponds to a spectral line or rather to a possible intermittent phase modulated signal. Only longer time series produced by coupled ocean-atmosphere and, possibly ice, numerical models can answer to this question when runs 500 year longer or more are available.

The spectral analysis of the Mediterranean SST time series also indicates the occurrence of higher frequency significant peaks at 6.3, 3.9, 2.8 and 2.2 years likely to correspond to harmonic phase-coherent oscillation. The two higher frequency peaks are linked to the scale of variability of the ENSO's quasi-biennial and low-frequency modes.

Change of Mediterranean physical characteristics in the last 50 years and its impact in the North Atlantic

When we move on the analysis of the last fifty year, we have more data readily available for the entire water column and almost regularly distributed in space and in time all over the Mediterranean Sea. Therefore using these datasets we can obtain more reliable and robust results. Many papers have pointed out the relevant warming of the surface (Marullo *et al.*, 2009) and intermediate water, but in particular the warming trend of the deep water layer (Rixen *et al.*, 2005). In particular, in the Western Mediterranean Sea the heat and salt content have been increasing almost steadily during the last 50 years, with possible combined effect of anthropogenic greenhouse effects, to a decrease in precipitation since the 1940's (Bethoux *et al.*, 1998), and to man-induced reduction of the

freshwater inflow for agricultural purposes (Rohling and Bryden, 1992). The observed increase of temperature and salinity of LIW (6.8×10^{-3} °C yr^{-1}, 1.8×10^{-3} yr^{-1}) is about twice the trend observed in the deep layers (3.6×10^{-3} °C yr^{-1}, 1.1×10^{-3} yr^{-1}), which is also superimposed to a strong interannual variability explained by year-to-year changes of the newly formed Western Mediterranean Deep Water (WMDW).
It is important to note that this warming is not only a peculiar characteristic of the Mediterranean Sea, but it is also observed at global scale. Over the period 1961 to 2003, global ocean temperature has risen by 0.10°C from the surface to a depth of 700 m, in which is stored the two-thirds of the energy absorbed (Levitus *et al.*, 2005). Polyakov *et al.* (2005) have observed that a multi-decadal variability on time scales of 50, 80 year is prevalent in the upper 3000 m of the North Atlantic Ocean and a general warming trend of 0.12°C per decade over the last 55 years was observed. This value is greater than the observed value at global scale over the period 1961-2003. Moreover, regarding the warming of the intermediate layer, including MOW, in the North Atlantic, by a comprehensive reanalysis of hydrographic sections taken from the 1920s through the 1990s, show that the largest statistically significant changes occur on pressure surfaces between 1000 and 2000 decibars (dbars). Over this pressure range and for latitudes between 32° S and 36° N, temperatures have warmed by 0.5°C per century. Studies of long-term changes in hydrographic sections that slice through the subtropical North Atlantic have consistently revealed a maximum warming near the base of the thermocline, located at 1000–1200m (Potter and Lozier, 2004).
Furthermore, looking the contribution of the Mediterranean waters on the North Atlantic warming, recently Gonzalez-Pola *et al.* (2005) have focalized their attention on the evolution of the intermediate water masses, corresponding to the northeastern branch of MOW, in the southeastern corner of the Bay of Biscay for the 1992-2003 period. They found a warming trend of 0.02°C and an increase of 0.005 in salinity per year, concluding that this area has warmed up during the last decade at rates from two to six times greater than those observed in the Atlantic during the last century. Moreover, two recent papers of Millot *et al.* (2006), regarding data analysis within the Strait of Gibraltar and in particular at Camarinal Sill South, point out an anomaly warming and salinification, from the early 2000s to 2008, corresponding to ~0.3°C and to ~0.06 respectively. This warming is clearly seen in the Gulf of Cadiz, where changes in water properties of MOW outflow were found, with an average value of 0.16°C/decade and 0.05 in salinity per decade over the last 50 years (Figure 3; Fusco *et al.*, 2008).

Conclusion

The Mediterranean Sea, parallel to the global ocean, is performing a relevant trend to warming. The peculiarity of this basin puts at risk its own biogeochemical system, rendering this ocean basin an hot-spot for the future climate change (Giorgi, 2006; Bindoff *et al.*, 2007). Also from the analysis of the North Atlantic water masses characteristics and in particular from those influenced by the spreading of the Mediterranean water, we can deduce indirectly that within the Mediterranean basin some strong warming is occurring. Moreover, if we consider the North Atlantic and the Mediterranean Sea (Artale

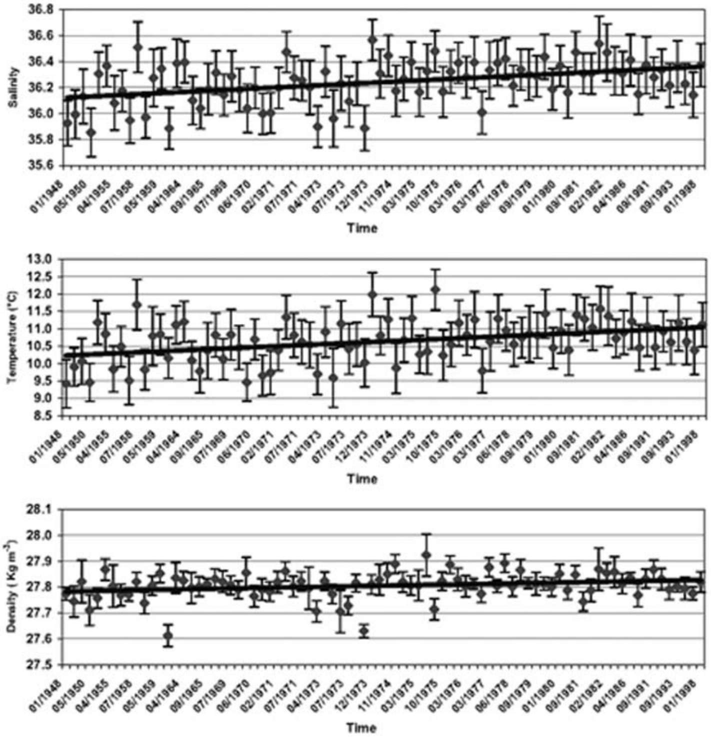


Figure 3. Trend of salinity, temperature and density of MOW at 1200 meter in the Gulf of Cadiz (Fusco et al., 2008).

et al., 2006) as unique oceanographic system, then the physical processes within the strait play a key role to determine the exchange of freshwater and salt water between marginal seas and the open ocean. In particular they determine, beside the hydrological tracers characteristic of the inflow/outflow, the delay time of the advection of the salt and freshwater anomaly within the internal circulation of North Atlantic, introducing a fundamental limiting factor. In fact it's well known that the MOW is one of the intermediate-type water mass observed, between 800-1200 m, in the North Atlantic, it is composed by a mixture of LIW and deep waters produced within the Mediterranean basin and flows in the Atlantic Ocean through the narrow Strait of Gibraltar, with a mean volume exchange of about 1 Sv. However the impact of this water, in agreement with previous studies (e.g., Rahmstorf, 1998), on the strength of the Atlantic thermohaline circulation is relatively small, however Artale *et al.* (2002 and 2006) demonstrate that the intermediate water related to the advection of the MOW in the North Atlantic, contribute on the variability of the North Atlantic Thermohaline Circulation.

In conclusion, the Mediterranean Sea is not an isolated ocean basin but an important component of the North Atlantic circulation, afterward it is easy to explain the different behaviour of SST in the last decades and the meridional and zonal pattern of AMO either. Furthermore, the Mediterranean SST should be considered in future near-term climate projections as a proxy of a mechanism that, depending on its behavior, can act either constructively or destructively with the region's response to anthropogenic influence, temporarily amplifying or mitigating regional climate change. For example, the trend related to the period 1980-2009 (see Figure 2) seems that the AMO are amplifying the anthropogenic influence.

Bibliography

Arbic B.K., and Owens W.B. (2001). Climatic warming of Atlantic intermediate waters. Journal of Climate 14(20): 4091–4108.

Artale V., Calmanti S., and Sutera A. (2002). North Atlantic THC sensitivity to Mediterranean waters. Tellus - Series A, 54(2): 159-174.

Artale V., Iudicone D., Santoleri R., Rupolo V., Marullo S., and D'Ortenzio F. (2002). Role of surface fluxes in ocean general circulation models using satellite sea surface temperature: Validation of and sensitivity to the forcing frequency of the Mediterranean thermohaline circulation. Journal of Geophysical Research 107: C8.

Artale V., Calmanti S., Malanotte-Rizzoli P., Pisacane G., Rupolo V., and Tsimplis M. (2006). The Atlantic and Mediterranean Sea as connected systems. In Mediterranean climate variability, Lionello P., Malanotte-Rizzoli P., and Boscolo R. (Eds.). Elsevier (Amsterdam). pp. 283-323.

Artale V., Calmanti S., Carillo A., Dell'Aquila A., Herrmann M., Pisacane G., Ruti P.M., Sannino G., Struglia M.V., Giorgi F., Bi X., Pal J.S., and Rauscher S. (2009). An atmosphere-ocean regional climate model for the Mediterranean area: assessment of a present climate simulation. Climate Dynamics 35(5): 721-740.

Bethoux J.P., Gentili B., Raunet J., and Tailliez J. (1990). Warming trend in the Western Mediterranean Deep Water. Nature 347: 660-662.

Béthoux J.P., Gentili B., and Taillez D. (1998). Warming and freshwater budget change in the Mediterranean since the 1940s, their possible relation to the greenhouse effect. Geophysical Research Letters 25: 1023–1026.

Bindoff N., Willebrand J., Artale V., Cazenave A., Gregory J., Gulev S., Hanawa K., Le Quere C., Levitus S., Nojiri Y., Shum C.K., Talley L., and Unnikrishnan A. (2007). Observations: oceanic climate change and sea level. Climate Change 2007: The Scientific Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon S. (Ed.). Cambridge University Press (New York).

Calmanti S., Artale V., and Sutera A. (2006). North Atlantic MOC variability and the Mediterranean outflow: a box-model study. Tellus 58A: 416-423.

Curry R., Dickson B., and Yashayaev I. (2003). A change in the freshwater balance of the Atlantic Ocean over the past four decades. Letters to Nature 426: 826–829.

Enfield D.B., Mestas-Nuñez A.M., and Trimble P.J. (2001). The Atlantic multidecadal oscillation and its relation to rainfall and river flows in the continental US. Geophysical Research Letters 28: 2077–2080.

Fusco G., Artale V., and Cotroneo Y. (2008). Thermohaline variability of Mediterranean Water in the Gulf of Cadiz over the last decades (1948-1999). Deep-Sea Research I 55: 1624–1638.

GIORGI F. (2006). Climate change Hot-Spots. Geophysical Research Letters 33: L08707.

LEVITUS S., ANTONOV J.I., AND BOYER T.P. (2005). Warming of the World Ocean, 1955-2003. Geophysical Research Letters 32: L02604.

MALANOTTE-RIZZOLI P., MANCA B.B., RIBERA D'ALCALÀ M., TEOCHARIS A., BRENNER S., BUDILLON G., AND OSZOY E. (1999). The eastern Mediterranean in the 80's and in the 90's: the big transition in the intermediate and deep circulations. Dynamics of Atmospheres and Oceans 29: 365– 395.

MARIOTTI A., STRUGLIA M.V., ZENG N., AND LAU K.M. (2002). The hydrological cycle in the Mediterranean region and implications for the water budget of the Mediterranean Sea. Journal of Climate 15: 1674–1690.

MARULLO S., BUONGIORNO NARDELLI B., GUARRACINO M., AND SANTOLERI R. (2007). Observing the Mediterranean Sea from space: 21 years of Pathfinder-AVHRR sea surface temperatures (1985 to 2005): re-analysis and validation. Ocean Science 3: 299–310.

MARULLO S, ARTALE V., AND SANTOLERI R. (2009). The SST multidecadal variability in the Atlantic-Mediterranean region and its relation to AMO. Work in progress.

MILLOT C., FUDA J.L., CANDELA J., AND TBER Y. (2006). Large warming and salinification of the Mediterranean outflow due to changes in its composition. Deep-Sea Research I 53: 656–666.

NAPOLITANO E., SANNINO G., ARTALE V., AND MARULLO S. (2003). Modelling the baroclinic circulation in the area of the Sicily Channel: the role of stratification and energy diagnostics. Journal of Geophysical Research 108(C7): 3230.

PINARDI N., AND MASETTI E. (2000). Variability of the large scale general circulation of the Mediterranean Sea from observations and modelling: a review. Palaeogeography, Palaeoclimatology, Palaeoecology 158: 153–173.

POEM GROUP (1992). General circulation of the eastern Mediterranean. Earth Science Reviews 32: 285–309.

POLYAKOV I.V. *ET AL.* (2005). One more step toward a warmer Arctic. Geophysical Research Letters 32 L17605.

POTTER R.A., AND LOZIER M.S. (2004). On the warming and salinification of the Mediterranean outflow waters in the North Atlantic. Geophysical Research Letters 31(1): L01202.

RAHMSTORF S. (1996). On the freshwater forcing and transport of the Atlantic thermohaline circulation. Climate Dynamics 12: 799–811.

RAHMSTORF S. (1998). Influence of Mediterranean Outflow on climate. Eos 79: 281–282.

RAYNER N.A., PARKER D.E., HORTON E.B., FOLLAND C.K., ALEXANDER L.V., ROWELL D.P., KENT E.C., AND KAPLAN A. (2003). Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. Journal of Geophysical Research 108(D14): 4407.

REID J.L. (1979). On the contribution of the Mediterranean sea outflow to the Norwegian Greenland sea. Deep-Sea Research, Part A: Oceanographic Research Papers, 26(11 A Pt A): 1199–1223.

RIXEN M., BECKERS J.M., LEVITUS S., ANTONOV J., BOYER T., MAILLARD C., FICHAUT M., BALOPOULOS E., IONA S., DOOLEY H., GARCIA M.J., MANCA B., GIORGETTI A., MANZELLA G., MIKHAILOV N., PINARDI N., AND ZAVATARELLI M. (2005). The Western Mediterranean Deep Water: A proxy for climate change. Geophysical Research Letters 32 L12608.

ROETHER W.B, MANCA B., KLEIN B., BREGANT D., GEORGOPULOS D., BEITZEL V., KOVACEVIC V., AND LUCCHETTA A. (1996). Recent changes in the Eastern Mediterranean deep waters. Science 271: 333-335.

ROHLING E.J., AND BRYDEN H.L. (1992). Man-induced salinity and temperature increases in the Western Mediterranean deep water. Journal of Geophysical Research 97(C7): 11191–11198.

ROUSSENOV V, STANEV E., ARTALE V., AND PINARDI N. (1995). A seasonal model of the Mediterranean Sea General Circulation. Journal of Geophysical Research 100(C7), 13515-13538.

SEND U., FONT J., KRAHMANN G., MILLOT C., RHEIN M., AND TINTORE V. (1999). Recent advances in observing the physical oceanography of the western Mediterranean Sea. Progress in Oceanography 44: 37– 64.

STRUGLIA M.V., MARIOTTI A., AND FILOGRASSO A. (2004). River discharge into the Mediterranean sea: Climatology and aspects of the observed variability. Journal of Climate 17: 4740-4751.

CLIMATE IN THE MEDITERRANEAN AREA DURING THE LAST MILLENNIUM

Dario Camuffo and Chiara Bertolin
Institute of Atmospheric Sciences and Climate (ISAC), National Research Council of Italy (CNR), Padua (Italy)
e-mail: d.camuffo@isac.cnr.it

Key-words: *instrumental observations, documentary sources, pictorial sources,"proxy data", sea level rise*

Abstract

In this paper, the birth of first instrumental observations on atmospheric parameters by the "*Accademia del Cimento*" is showed. The first regular observations on air temperature started in Italy in 1654 and continued until present time whereas observations on precipitation begun in 1716. For areas and periods where direct measures are lacking, information on past climate can be inferred from different types of proxies. This paper considers proxies based on documentary written sources (both archival and narrative), pictorial sources - used to infer changes in sea-water level in Venice, basing on paintings by Veronese, Canaletto and Bellotto who used the optical "*camera obscura*" technique - as well as dendroclimatic data. The long series of instrumental observations show that, in the Mediterranean area, air temperature and precipitation were characterised by swings of different period that showed to change phase several times. Even the correlation between Mediterranean and global scale changed with time, although in the last 60 years a stable positive correlation has been detected. In the Mediterranean area both temperature and rainfalls had large changes in the past, sometimes to an extent not smaller than nowadays, thus leaving open any hypothesis on future scenarios of Mediterranean climate.

Instrumental observations

The earliest instrumental observations on atmospheric parameters were carried out by the Florentine "*Accademia del Cimento*" (Academy of Trials) along the tracks of the new interest for science coming from Galileo's findings. The first thermometer providing scientific records of air temperature was built in 1641; it was the first spirit-in-glass thermometer and was named the "Little Florentine thermometer". First regular records of air temperature measured at intervals of few hours started in 1654 and lasted to 1670, when an intervention by Inquisition stopped that practice. This implies that a serious gap

exists in the time-series of air temperature until 1716, and recording of atmospheric parameters spread to many European sites.
The available series of observations need to be carefully checked to find out erroneous data on the basis of information on the technical features of the sensors, position and exposition to sun of the measurement sites, as well as by comparison with data from recent times. All series of data are reported as anomalies (i.e., differences from the average values calculated on the corresponding data recorded during 1961-1990). This approach allows to reduce the influence of local weather and to use data from measurements made at a fixed time of each 24-hour period, by comparing the available data with those recorded at the same daytime during the reference 30 years. On this basis, it is possible to obtain centuries-long time series as well as calculating means over comparatively large geographic areas when enough information is available from distinct sites. It has been therefore possible to reconstruct long term time-series of air temperature and precipitation in sites of northern, central and southern Italy (e.g., Padua, Bologna, Florence, Vallombrosa, Palermo) as well as in countries of the NW Mediterranean and adjacent areas (Portugal, Spain and France). Unluckily, fewer and less accurate data are available in the eastern Mediterranean, although efforts have being made to recover data from Greece and the Slavic coast. Only discontinuous and inhomogeneous data series exist for Anatolia and the North African coast.
It is worth noting that, in this framework, high-quality records are needed since signal should not be masked by "noise" determined by various sources of uncertainty (Brohan *et al.*, 2006; Knight *et al.*, 2009). For instance, since 1850 global air temperature increased by 0.6°C, and the systematic bias due to the screens where the thermometer is lodged is estimated to be +1.5°C by the Italian Air Force in sunlight days with weak winds, and –0.5°C in nights with clear sky (Cicala, 1970), while WMO estimated that in the worst cases the bias may range between +2.5°C and – 0.5°C (WMO, 1983).

Indirect data ("proxies")

In areas with inadequate instrumental coverage, it is only possible to use indirect data ("proxies"). The word "proxy" is derived from the French-English term "*procuracie*", in turn coming from the Middle Age Latin "*procuratio*" (i.e., "administration", also including to carry out some duties on behalf of others), which herewith means an indirect observation based on the observation of natural phenomena or any documentation left by man, that could be used instead of real instrumental observations, when they do not exist..
Proxies are indirectly inferred from other environmental variables whose relation with the one to be estimated is known. If the proxy depends from only one variable, and with one-to-one correspondance, the transformation is quite simple and reliable. If the proxy depends upon two or more variables, and with multifold correspondance, the transformation is uncertain (Camuffo *et al.*, 2010a).
Only proxies are, however, available when instrumental observations are missing. In this paper they are used to reconstruct the Mediterranean climate during the last millennium. We used proxies of three kinds: data from documentary sources, from paintings and dendroclimatic data.

Proxies from documentary sources
We can distinguish the climatic proxies from documentary sources according to the types of concerned writings, tales or administrative sources. As administrative documentation, we mean all what public employees wrote on specific events that they had to exactly report as part of their duties. Tales can also describe climatic events either directly witnessed or heard from other people, and the latter evidences are usually less reliable. Cultural, social and subjective factors can influence the author's judgement on how much a given event is severe, thus it is necessary evaluating both the author's general reliability as well as of the description of the reported event.
The reported events allow to roughly assess air temperature, rains and other atmospheric parameters in a given area and period. Such qualitative assessment is converted to a semi-quantitative scale where the events corresponding to the exceptionally high and low values of a given atmospheric parameter are respectively labelled +3 and -3, whereas those close to normal conditions (in the described past period) are labelled "0". If we assume that the variability of the examined atmospheric parameters around their means have not changed with time, and we impose on the ancient proxy data to have the same standard deviation of present-day instrumental observations, it is possible to transform qualitative indexes of past temperature or precipitation in "modern" units, e.g. °C and mm of precipitation. If we have periods with an overlap between proxy data and instrumental observations, we can also assess the accuracy of the above-mentioned assumptions.
One of the most relevant outputs of this study is the combined time series of air temperature in Italy based on instrumental measures and written sources. In Figure 1 the reconstructed trend of the winter air temperature during the last 1000 years is shown.

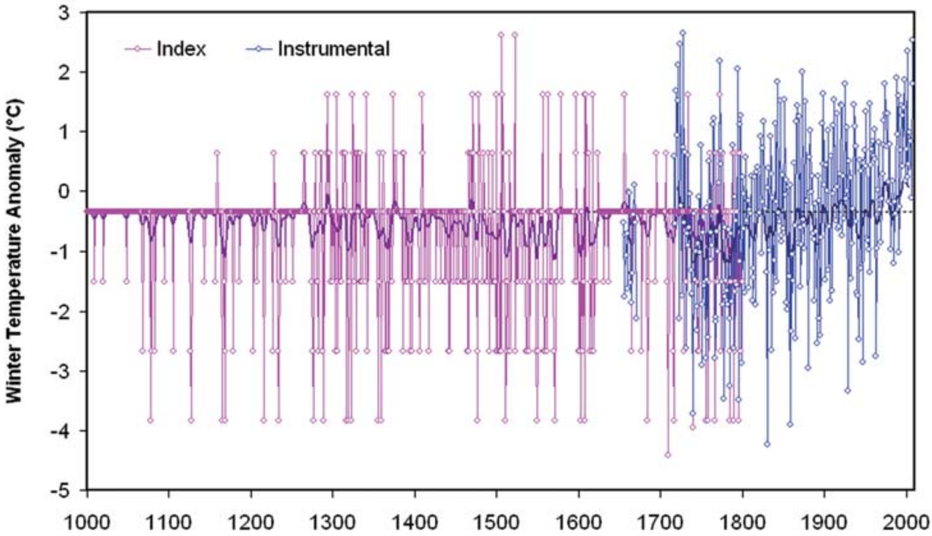


Figure 1. Reconstruction of winter air temperature in Italy from year 1000 AC to the present time. The pink line shows the time series based on climatic proxies from written sources. The blue line shows the series from instrumental observations. The black thick line is derived by using the Hamming filter on all data. The "zero" or "normal" level of the climatic proxies is assumed being equal to mean temperature calculated from the entire series of instrumental data.

Proxies from pictorial sources

The reconstruction of environmental data from pictorial sources is often subjective. An important exception is the monitoring of relative sea level rise in Venice, thanks to the use of the optical *camera obscura* for painting buildings. The optical *camera obscura* was used to outline the pictured buildings on their tables before adding colours. Indeed, this tool projects the figure on a surface (e.g. sheets of paper, canvas); thus, if the artist accurately draws the lines, the oil paints are something like ancient “photos” taken before the development of this technique by Daguerre and others (1837).

The pictures are, however, to be compared with an independent index(s) showing the sea level in order to estimate its change over time. A useful marker to monitor the average level of high tides is the presence of algae belt on the external lower surfaces of the Venetian buildings that was named “*comune marino*” and officially taken as reference of the sea level both for buildings and urban development. If the algae belt is accurately pictured on oil paints together with details of buildings, we can measure how much its level differs from the present one and therefore estimate the sea level changes due both to subsidence and eustatism. Luckily, in Venice several painters accurately used the mentioned technique, i.e. Paolo Veronese (1528-1588), Giovan Antonio Canal named “Canaletto” (1697-1768), and his nephew Bernardo Bellotto (1721-1780).

Measurements of the “*comune marino*” level are to be corrected to take into account of the local environmental features at the painter’s time. This implies the excess of surface wetting, due both to the waves originated by boat engines and the increased water exchange between sea and lagoon, to be removed. After appropriate corrections, we therefore estimate that the sea level has increased by 82 ± 9 mm since the Veronese’s time and by 61 ± 10 mm since that of Canaletto (Figure 2). In the period from Veronese (1571) to Canaletto (middle of 18^{th} century) the sea level rose by 1.2 mm/year, mainly due to land subsidence. Since Canaletto’s time the relative sea level rise has uniformly been 2 mm/year due both to subsidence and eustatism, roughly in equal proportions (Camuffo and Sturaro, 2003; Camuffo, 2010).

Dendroclimatic proxies

Dendrochronology allows reconstructing the past climate from the annual growth rings of trees. In optimal environmental conditions (heat, sun light for photosynthesis, water), trees grow faster and their annual rings are large and not thick. In adverse climate conditions (cold temperature, lack of water), the situation is reversed and the annual rings are thin and thick. All this allows monitoring climatic changes over years. This technique would be useful to monitor changes over a few thousands years but actually is restricted to periods not exceeding a few centuries because it is difficult to find exceptionally old trees in the present days forests. In Italy a good climate reconstruction, based on dendrochronological data, exist for the last centuries but information is poor for the climate during the last millennium.

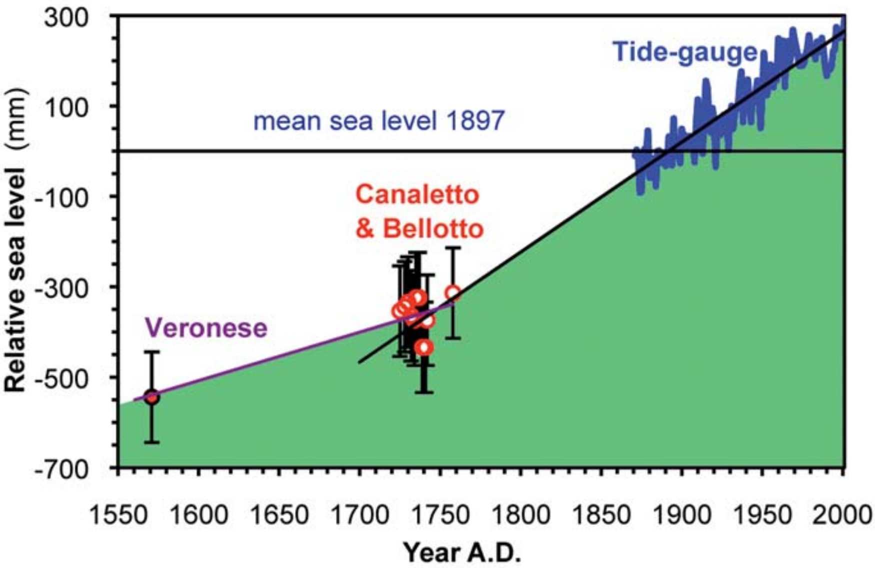


Figure 2. Time trend of the sea level in Venice based on proxies from the "comune marino" in paintings by Veronese, Canaletto and Bellotto, as well as appropriate instrumental measures in recent times.

Conclusions: climate variations in the NW Mediterranean area

Long-term time-series of instrumental observations show that both air temperature and precipitation always varied in the Mediterranean area according to oscillations of different periodicity (35 y for temperature and 70 y for rain). Moreover, the relationships between these two variables changed during time, for instance the climate being warm-moist, cold-moist, warm-dry, cold-dry. The amplitude of swings in these parameters was in some periods not smaller than nowadays (Figure 3). We may therefore even suspect that the foreseen dismal trend with increasing temperature and aridity could actually get weaker or reverse.
After the 2007 ICCP report (Le Treut, 2007), it results that air temperature have been globally increasing since 1850, with a sharp increase in the last decades, while in the Northern Hemisphere the precipitation trend during the same period is less clear but the sharp decrease recorded in the Mediterranean area shows a shift towards a warm-dry climate. Although it is not correct comparing changes at global and regional scales, we must wonder to what extent the general circulation at the Global Scale influences the Mediterranean climate. For this purpose, we compared climatic data from the 2007 ICCP report with those gathered during our study.
Comparison among data from the Mediterranean area and the Northern Hemisphere shows that over the course of time they had different relationships, from fully positive to fully negative correlation (with coefficients of determination R being +1 and -1, respectively). All this means that in some periods the Mediterranean climate is connected to the Global Scale, but in other periods the situation reversed, without any clear explanation for

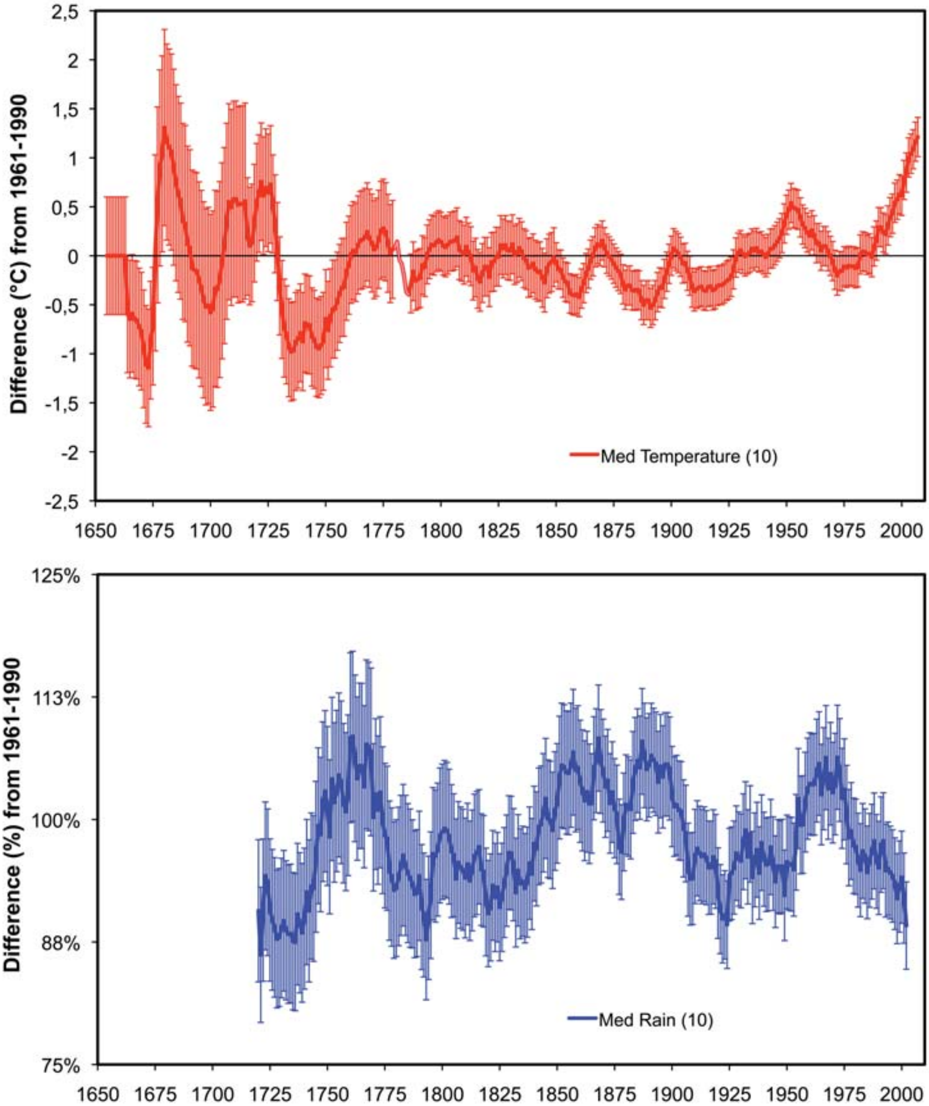


Figure 3. Air temperature anomalies, as °C degrees (red line), and for precipitation, as mm (blue line), calculated by comparison with the analogous means in the Western Mediterranean during the 1961-1990 reference period. Thin lines show the error bars.

such change. Since 1950 the Mediterranean climate and that of the Northern Hemisphere are in positive correlation and this is the longest period showing such persistent situation. Looking back to the past we could expect the reversion of the trend, implying that in the Mediterranean Sea the climate would get better (no further or slower warming and more abundant precipitation).

These doubts will be perhaps solved in future studies, but especially by the future climate evolution that might be different from model runs.

Acknowledgements

The findings presented in this paper have been obtained thanks to the EU funded projects MILLENNIUM (Co 017008-2) and Climate for Culture (Grant 226973).

Bibliography

Brohan P., Kennedy J.J., Harris I., Tett S.F.B., and Jones P.D. (2006). Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Journal of Geophysical Research 111: 21 pp.

Camuffo D. (2010). Paul Véronèse, Antonio Canal, dit Canaletto, et Bernardo Bellotto: un témoignage pictural de la hausse du niveau de la mer à Venise et une estimation quantitative du taux de submersion au cours des 437 dernières années. Revue d'Histoire Moderne et Contemporaine 57-3: 92-110.

Camuffo D., and Sturaro G. (2003). Sixty-cm submersion of Venice discovered thanks to Canaletto's paintings. Climatic Change 58: 333-343.

Camuffo D., and Sturaro G. (2004). Use of proxy-documentary and instrumental data to assess the risk factors leading to sea flooding in Venice. Global and Planetary Change 40: 93-103.

Camuffo D., Bertolin C., Barriendos M., Dominguez-Castro F., Cocheo C., Enzi S., Sghedoni M., della Valle A., Garnier E., Alcoforado M.J., Xoplaki E., Luterbacher J., Diodato N., Maugeri M., Nunes M.F., and Rodriguez R. (2010a). 500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. Climatic Change 101 (1-2): 169-199. DOI: 10.1007/s10584-010-9815-8.

Camuffo D., Bertolin C., Diodato N., Barriendos M., Dominguez-Castro F., Cocheo C., della Valle A., Garnier E., and Alcoforado M.J. (2010b). The Mediterranean climate: how will it respond to Global Warming? Climatic Change 100: 137-142. DOI 10.1007/s10584-010-9817-6.

Cicala A. (1970). Meteorologia e strumenti. Libreria Editrice Universitaria Levrotto & Bella (Torino). 199 pp.

Knight J., Kennedy J.J., Folland C., Harris G., Jones G.S., Palmer M., Parker D., Scaife A., and Stott P. (2009). Do global temperature trends over the last decade falsify climate predictions? In State of the Climate in 2008, Peterson T.C., and Baringer M.O. (Eds.). Special Supplement of Bulletin of the American Meteorological Society 90(8): S75–S79. Retrieved 2009-09-08.

Le Treut H., Somerville R., Cubasch U., Ding Y., Mauritzen C., Mokssit A., Peterson T.C., and Prather M. (2007). Historical overview of climate change. In Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M., and Miller H.L. (Eds.). Cambridge University Press (Cambridge).

WMO (1983). Guide to meteorological instruments and methods of observation. Fifth Ed. WMO-No8 Secretariat of the World Meteorological Organization, Geneva (Switzerland).

STURGEON AND CAVIAR TRADE AT THE LOWER DANUBE – A HISTORICAL APPROACH TO A CONTEMPORARY PROBLEM

Constantin Ardeleanu
"Dunărea de Jos" University of Galaţi (Romania)
e-mail: Constantin.Ardeleanu@ugal.ro

Key-words: *history of fishing, caviar trade, sturgeons, endangered species*

Introduction and objectives

In April 1998, following alarming reports of scientists and environmental NGOs, all sturgeon species were listed in the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).[1] As the Black Sea shelf zone is one of the most important habitats for the endangered species of *Acipenseridae*, and the Danube River is a favourite area for migratory sturgeons during the spawning periods,[2] the riparian countries play an important part in the struggle to conserve sturgeon populations, threatened to complete extinction by over-fishing and degradation of their natural habitation. In the past years, several meetings involving fishery scientists, fishery managers, law enforcements institutions, fishermen associations and CITES administration resulted in the creation of a Black Sea Sturgeon Management Action Group and later on in the adoption of a Regional Strategy for the Conservation and Sustainable Management of Sturgeon Populations of the NW Black Sea and Lower Danube River in accordance with CITES. In 2006, the riparian countries banned commercial fishing of all wild sturgeon species for the next ten years and hopefully adopted restocking programmes for sturgeon populations.[3]

These desperate attempts to conserve sturgeon species after a period of veritable biogenocide, common in most former communist states (with endemic corruption, lack of adequate legislation, desire of rapid enrichment of transition upstarts, all doubled by defective or inappropriate restocking policies), come after a period in which the political, eco-

1 C. Raymakers (2006), "CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora", pp. 53-65.
2 References relative to the migration habits of sturgeons in A. Ciolac (2006), "Migration of fishes", pp. 155-159.
3 M. Paraschiv, R. Suciu, and M. Suciu (2006), "Present state of sturgeon stocks", pp. 152-158; cf. also *Regional Strategy for the Conservation and Sustainable Management of Sturgeon Populations of the N-W Black Sea and Lower Danube River*, Tulcea, 26 November 2003 and J. Bloesch (Ed.) (2006), *Action Plan,* Nature and environment, No. 144.

nomic and environmental context contributed enormously to the contemporary problems. Thus, in the past two centuries, several anthropogenic factors have been responsible for the decline of Black Sea and Danube sturgeon populations. The aspects with the most ruinous effects are: a) the massive deforestation of the areas in the Danube River basin; b) the construction of dikes, which destroyed flood plains, the habitual spawning places for sturgeons; c) the completion of the Iron Gates dam in the 1980s, which prevented large sturgeons from reaching to upstream spawning sites; d) pollution, as the industrial and agricultural development of the riparian countries resulted in an increase of water pollution in the Danube River basin, affecting the entire biota; e) water losses due to hydrotechnical constructions, such as dams and irrigation or shipping canals, which altered the flow of the Lower Danube etc.[4]

Beyond these extreme alterations in the environmental conditions, a human activity which greatly influenced the sturgeon populations in the Lower Danube was over-fishing. Although certain authors present it as "peasant food", caviar, the unfertilised roes of sturgeon, has always been a well-renowned delicacy, a luxury product which provided important revenues to the fishermen or merchants who dealt with catching sturgeons or harvested and traded their roes. The sizes of certain species of sturgeons and the quality of their meat have been other elements which made sturgeon fishing a very profitable enterprise along the centuries. Starting from these premises, this paper aims to present, on the basis of available historical evidence, the evolution of sturgeon fishing and caviar trade at the Lower Danube (i.e., the river sector stretching from the Danube Mouths to the Iron Gates dam), with the necessary references to the local political and economic conditions which affected the status of sturgeon stocks in the river and its main tributaries.

Narrative information on sturgeon and caviar trade at the Lower Danube

Although archaeological data and written sources allow researchers to state that sturgeons had had a great economic importance for local inhabitants as early as prehistorical, ancient and early medieval times, reliable information is too sporadic and contingent to permit any definite estimates. More suitable for analysis is the period beginning with the 15th century, when official documents and travelogues allow more precise quantitative and qualitative assessments, but also when the political context along the Lower Danube provided more efficient conditions for the exploitation of the rich fish resources (i.e., the right bank of the river was directly controlled by the Ottoman Empire, whereas the left bank belonged to the Romanian Principalities of Wallachia and Moldavia, which gradually fell under the Porte's suzerainty).

Fishery specialists consider that six anadromous species of *Acipenseridae* migrated from the Black Sea into the Danube for spawning: *Acipenser gueldenstaedti* – Danube or Russian sturgeon, *A. nudiventris* – Fringebarbel or ship sturgeon, *A. ruthenus* – sterlet, *A. stellatus* – stellate or starred sturgeon, *A. sturio* – common or Atlantic sturgeon and

4 N. Bacalbaşa-Dobrovici (1997), "Endangered migratory sturgeons", pp. 201-207; cf. also J. Bloesch (Ed.), *Action Plan*, pp. 43-49; N. Bacalbaşa-Dobrovici and N. Patriche (1999), "Environmental studies", pp. 114-115.

Huso huso – beluga or great sturgeon. Documentary sources mention that all these species were an inexhaustible treasure of the river, being caught all along the Lower Danube, but also upstream of the Iron Gates, as far as Bavaria. Sturgeons also thrived in tributaries of the Lower and Middle Danube, including large rivers such as Drava, Sava, Tisza, Mureș, Sireth or Pruth.[5]

Taking into account the number and sizes of the sturgeons, especially of the beluga, one of the most usual fishing methods was to use weir structures constructed from wooden posts, as described by the Syrian chronicler Paul of Aleppo. Travelling on the Danube at the middle of the 17th century, Paul reached the port of Kilia, in the environs of which there were fourteen traps "for catching fish, and in particular the sturgeon". The devices had to be reconstructed each year, as upon the thawing of the ice, "the stream carries away the stakes, by the violence of its overflow". The construction procedure was as following: the workmen cut thousands of rafters of wood, brought them to the Danube, planed off the heads like spear-points, and drove them into the ground, "in a row from end to end, leaving only, on one side, an opening sufficient for the passage of a boat; whilst at the further end is a narrow channel enclosing a kind of small house, all of wooden stakes fastened in the ground. When the morona or other fish approach this enclosure, they are made, by an excellent contrivance, to fall into it; and the company of persons charged with this occupation strike them with long spears, till they are killed; for the fish have no means of retreating".[6] Other minute details of these fishing weirs are provided in the description of the Turkish voyager Evlyia Çelebi. Travelling on the Danube in 1658-59, Çelebi noticed large heaps of rafters and two thousand peasants working, with two hundred boats, to fix them into the river bed. "By means of long, bifurcated poles, they place at the bottom of the water nets knit from vines and attach them to the rafters. When these nets reach to the surface of the water, the Danube gets the aspect of a river crossed by mats, so that not even fish the size of a palm can swim beyond these nets".[7] A similar type of fishing weir was described at Silistria, where fir, oak and hornbeam rafters, over fifty meters long, were stuck in the river bed. The workers bound to them twig wattles, starting from the bottom of the river, leaving only an opening fitted with a wattle door, so as to allow ships to navigate. The trap was watched day and night by the contractor and his men, 100-200 people, who continuously took off the fish caught in the net.[8]

The Iron Gates was another favourable area for fishing large sturgeons, the river being quite narrow and having both deep holes and fords. The same Turkish traveller mentions that on a small stretch of the river, from the Iron Gates to the citadel of Fetislam (Cladova), a distance covered in two hours, there were 2-3,000 such traps, so that "no fish could escape, not even those the size of a palm". These devices were fishing weirs, but also fyke

---

5 For a presentation of sturgeons in the Middle and Upper Danube, see K. Hensel and J. Holčik (1997), "Past and current status of sturgeons", pp. 185-200.

6 *The travels of Macarius, patriarch of Antioch, written by his attendant archdeacon, Paul of Aleppo* (1836), vol. II, p. 420.

7 C.C. Giurescu (1964), *Istoria pescuitului,* vol. I, pp. 92-93; the whole description in *Călători străini despre Țările Române*, vol. VI, partea a II-a, *Evlyia Çelebi* (1976), pp. 442-443.

8 Giurescu, *Istoria pescuitului*, pp. 95-96; *Călători străini*, VI (II), pp. 373-375; for the importance of fishing during the Ottoman period, see M. M. Alexandrescu-Dersca Bulgaru (1971), "Pescuitul în delta Dunârii", t. II, pp. 267-282.

nets specially designed for large sturgeons, like that presented by the Austrian general, of Italian origin, Marsigli. The device was made of six thick rafters united in three pairs and consolidated with horizontal boards. The device resembles fishing gears mentioned in the second half of the 19th century, such weirs having 10-15 meters at the entrance and a sack of 1-1.2 meters at the end.[9]

Using these devices, placed all along the river, the sturgeon harvest was enormous. Thus, to refer to the above mentioned cases, Paul of Aleppo stated that in the previous years a "great capture of fish used to take place": in the morning of each day, from the beginning of July until mid November, fishermen caught at Kilia "from three and four hundred to seven hundred sturgeons".[10] The Italian monk Niccolo Barsi, who visited Moldavia in 1633-39, wrote that fishermen brought daily to Kilia 1,000-2,000 sturgeons; according to the estimates of a Romanian historian, based on the maximum price of fish revealed by reliable sources, fisherman caught each year, in the Kilia region, at least 25,000 belugas, assessment which concords with the information provided in 1762 by the French consul Peysonnel. As for Silistria, Çelebi stated that in the first day of fishing, 7000 smaller and larger fish were caught, among which 70 "imperial" belugas (i.e., very large), each measuring over five meters in length. Further down the Danube, near the island of Ada Kaleh, 50-100 belugas were caught daily at the end of the 17th century.[11]
As the fishing season was very long, lasting for at least seven months a year (sturgeons were caught when migrating from Danube to Black Sea and back), abundance and cheapness of very large sturgeons was constant in the 15th-18th centuries. An Italian missionary, bishop Bandini, who visited Moldavia in 1646, wrote that "the beluga and sheatfish caught here are of amazing sizes"; six years later, the Englishman Robert Bargrave noted that "sometimes, they catch such big fish, that they need 6-8 oxen to lift it on the shore (together with the trap)". Thus, fresh belugas, sometimes weighing several hundred kilos, could be bought for very low prices, "almost for nothing".[12]
One of the reasons which made sturgeons be very appreciated by fishermen, merchants and consumers alike was related to the multitude of products which could be obtained from this type of fish. In the first place, the meat was white and, according to a contemporary source, as tasty as veal. It was eaten fresh, but, most often, in order to be preserved and transported on long distances, it was salted, pressed with stones until "its moisture was cleared away" and then filled into large barrels. The back of the fish was very savoury, being smoked and turned into stockfish. The beluga was by far the most delicious of the sturgeons; besides its meat, the skin, gristle and fins were also sold on the fish market. From the swim bladder, fishermen made fish glue, used for clearing the wine, whereas the tallow was also much sought after. But the roes, the tasty caviar, making up to a third of the sturgeons' weight, was the most important part. The roes were taken out and placed on a board, and the butchers, "having added to it a quantity of salt", set

9 Giurescu, *Istoria pescuitului*, p. 99; for the description, see L.F. de Marsigli (1744), *Description du Danube*, t. IV; other considerations in G. Antipa (1916), *Pescăria şi pescuitul în România*, pp. 663-664.
10 *The travels of Macarius*, p. 421.
11 Giurescu, *Istoria pescuitului*, pp. 88 sqq.
12 *Ibid.*, p. 25.

on it another board or plank, with large stones, to press out the blood and blue water. On becoming dry, the caviar was packed in barrels.[13]

During the 15th-18th century, sturgeons and caviar from the Lower Danube was exported "up to the bottom of Europe". Many ships came to Kilia, Ismail or Galatz "from Constantinople and the islands, to purchase the sturgeon, which they salt and stow in barrels: and in the same way they deal with the caviar, apart".[14] According to a different source, the fish caught were continuously being salted and specialised butchers prepared the refined caviar, for which fact, as Barsi mentions, "merchants come from Constantinople, Poland, Hungary, Wallachia and other countries to buy fish and to make provisions for their cities".[15]

One of the most important markets for sturgeons and caviar were the Saxon commercial centres of Braşov (Kronstadt) and Sibiu (Hermannstadt), whose inventory books also refer to the amount of medieval sturgeon fishing. Thus, in 1503 the merchants from Braşov imported from Wallachia 538.5 burdens (about 72 tons) of sturgeons, worth of 86160 aspers, and 12 burdens (about 1.6 tons) of caviar. In 1545, the quantities and values were smaller, yet as impressive: 126 burdens (17 tons) of beluga and 7 burdens (945 kilos) of caviar. The Moldavian exports to Braşov were also significant: in a ten months' interval, at the end of the 15th century, the sources record arrivals of 365 burdens (49 tons) of beluga and 4½ burdens (600 kilos) of caviar.[16] Sibiu was a smaller market for fish, as in year 1500 the local tradesmen purchased "only" 74½ burdens (10 tons) of beluga. Poland, especially the commercial town of Lemberg, was another favourite destination for the Danubian sturgeons: bishop Bandini wrote in 1646 that many thousand carts of fish were sent annually to Podolia, Russia, Ukraine and Transylvania. Important quantities were sometimes sent to Poland as part of the obligations assumed by the Moldavian princes towards the Polish kings. Thus, in 1436, hospodar Iliaş bound himself to send his suzerain 200 burdens (27 tons) of beluga.[17]

Constantinople was another key point in the sturgeon and caviar trade, as it collected the production of the Black Sea and redistributed it towards the entire Mediterranean. If caviar was very requested in Greece and the orthodox countries especially during the fasts, when Christians did not eat "anything with blood", it was also very popular among the more prosperous Italian cities. Thus, according to a recent research, the Lower Danube region was an important provider of sturgeons and caviar to the Constantinopolitan market, as well as to the Adriatic, where the products were transported on the maritime or Balkan land route-ways. The trade proved so profitable for the Serenissima's tradesmen that in the 17th century the Venetian *bailo* obtained from the Porte's suzerainty the authorization to appoint a consul at Kilia. As the Ottomans were not very willing to allow foreign merchants to trade directly in the Black Sea basin, the transports were usually shipped by Ottoman subjects, such as the Ragusans. Niccolo Barsi mentions

13 *The travels of Macarius*, pp. 420-421; Giurescu, *Istoria pescuitului*, pp. 100-101.
14 *The travels of Macarius*, p. 420.
15 *Călători străini despre Ţările Române* (1973), vol. V, p. 84.
16 Giurescu, *Istoria pescuitului*, pp. 247-248, 254-255.
17 *Ibid.*, p. 83.

that he met them at Kilia, where they were salting belugas and other sturgeons and preparing them for export[18].

Decline in sturgeon populations at the Middle and Lower Danube

The high demand for sturgeons and caviar and the intense fishing of all species of *Acipenseridae* resulted in a visible decline in fish populations as early as the 18th century. Thus, if great sturgeons used to mount from the Danube to the Theiss and thence to the Mureş tributary, a description of Transylvania in 1778 mentions that beluga was very rare and subsequently it was completely extinct from that river.[19] In 1835, the engineer Jules de Hagemeister wrote that beluga was less abundant in the Danube and thus caviar was very expensive and was entirely consumed in the capitals of Bucharest and Jassy.[20] The Romanian economist Ion Ionescu de la Brad also referred in 1867 to the reduced number of sturgeons in the Danube, so that upstream of the Iron Gates fishermen did not catch belugas anymore. Beyond the cataracts, large sturgeons were critically endangered and catches became sporadic. Thus, if in 1746 the annual catch of beluga was 27 tons on the 55 km long Danube section between Paks and Szeremle, in the 19th century large migratory sturgeons became an occasional catch in the Hungarian section of the Danube. According to some sources, only 16 belugas were taken in the Slowakian-Hungarian segment of the Danube between 1857 and 1957.[21]

During the 19th century, the Danube Delta fisheries still afforded profitable employment, and Vilkoff, at the mouth of that river, carried on an extensive trade in salted and dried fish, as well as in caviar. Although immense belugas were still caught, statistical sources show that the Danubian ports imported black caviar from Russia (which was then in possession of the Delta). It can be stated that the Romanian Principalities, although riparian to a large stretch of the river, could no longer cover the internal demand, as the important development of grains exports meant that more and more flood plains were enclosed with dikes. Another important mark of a diminished number of sturgeons is the huge difference in price between usual roes and caviar. If in the Middle Ages caviar was only 50% more expensive than other types of roes, in the 19th century the price of caviar was at least ten times higher than the roes of common fish.

After Romania took possession of the Danube Delta, by the Berlin Treaty of 1878, sturgeon over-fishing continued. The scientist to demonstrate the perilous situation of Lower Danube fish stocks was the biologist Grigore Antipa, who drew up several alarming reports, showing that the defective way of water management, the system of leasing fishing areas and over-fishing were responsible for an ichtiological disaster. The main problem was the savage exploitation of the fish resources by capitalist entrepreneurs, who leased the Danube Delta for a period of only 5 years and did nothing to secure a long time policy

---

18 For more information on the fish trade between Venice and the Romanian Principalities in the 17th century, cf. C. Luca (2007), *Ţările Române*, pp. 262-270.

19 Giurescu, *Istoria pescuitului*, pp. 33-34.

20 J. de Hagemeister (1835), *Mémoire*, p. 144.

21 Hensel and Holčik, "Past and current status", p. 191.

of fish protection. According to Antipa's example, in 1895, after the holiday of the Palm Sunday, in which Orthodox Christians are allowed to eat fish, the tenant of the Danube fishing threw away 50 tons of fish, so small that nobody bought it. In the same time, each year million of young sturgeons were caught in the nets for catching mackerel and were then thrown on the shore, not being good for anything.[22]
Although increased fluvial navigation did not allow anymore extensive use of fishing weirs, sturgeon species were still over-exploited by other types of fishing gears. Thus, according to Antipa, at the end of the 19th century only at the St. George branch of the Danube there were 20 million hooks for catching belugas.[23] Adding the fact that fishing was substantial all year long, but especially in spring, during the spawning period, and that sturgeons have a late sexual maturation, fish populations decrease rapidly. In this critical situation, Antipa draw up a fishing law which instituted a period of prohibition during the spawning time.
Despite these administrative measures, sturgeon stocks continued to diminish, a fact also visible in the decreasing annual catch: 685.5 tons a year for the period 1895-1908, 326 tons in the interval 1914-20, 287.8 tons between 1926-38 and 156 tons for the years 1941-46.[24] During the communist regime (1948-89), the centralized economy did not consider ecological criteria in sturgeon fisheries. The annual catch of beluga in the Danube varied from 20 tons to about 250 tons, with a drop off towards the last years of the period. Most fish were taken by Romania and the former Soviet Union, whereas the rest was shared by Bulgaria and former Yugoslavia. After 1989, in a completely different political, economic and social context, official data show an unlikely small catch (only 11.5 tons in 1994), although illegal fishing and the black market thrived. The economic interests of influent corrupt politicians resulted in the lack of adequate legislative measures to protect the ecosystem, although scientists and environmentalists continued to assert that the entire Danube biota was affected.[25] In terms of the sturgeon populations, not only the number and the size of the fish, but also its structure in the Danube River changed dramatically, and individuals are now much smaller and younger than in the past.

Conclusions

The last period has been extremely variable for the Danube sturgeons. If a good news comes from the fact that in the last years (especially after Romania and Bulgaria joined the EU), there have been implemented several projects aiming to repopulate the Danube with sturgeon stocks, a very recent Romanian law (317/October 2009) has changed the legal framework which condemned the commercial fishing of sturgeons and, according

---

22 G. Antipa (1895), *Studii asupra pescăriilor din România*, p. 44.
23 *Ibid.*, p. 43.
24 Giurescu, *Istoria pescuitului*, p. 35; for other statistical data, see R. Musse, "Les esturgeons de la mer Noire et leur pêche en Roumanie", *Annales de Géographie*, 1935, volume 44, No. 248, pp. 220-221 and Gheorghe I. Manea, *Sturionii. Biologie, sturionicultură şi amenajări sturionicole*, Bucureşti, 1980, pp. 109-112.
25 Bacalbaşa & Patriche, "Environmental Studies", p. 114.

to environmental NGOs, completely endangers all restocking policies. Thus, sturgeon overfishing, a constant of the past centuries in the Lower Danube River, is still a major threat in the struggle to save fish species 200 million years old.

Bibliography

Alexandrescu-Dersca Bulgaru M.M. (1971), "Pescuitul în delta Dunârii în vremea stăpânirii romane", *Peuce*, t. II, pp. 267-282.

Ali Mehmet M. (Ed.) (1976). *Călători străini despre Ţările Române*, *Evlyia Çelebi*, Bucureşti, vol. VI, partea a II-a.

Antipa G. (1895), *Studii asupra pescăriilor din România*, Bucureşti.

Bacalbaşa-Dobrovici N. (1997), "Endangered migratory sturgeons of the lower Danube River and its delta", in *Sturgeon Biodiversity and Conservation*, edited by V.J. Birstein, J.R. Waldman and W.E. Bemis, New York, pp. 201-207.

Bacalbaşa-Dobrovici N. and Patriche N. (1999), "Environmental studies and recovery actions for sturgeon in the Lower Danube River system", *Journal of Applied Ichthyology* 15: 114-115.

Bloesch J. (Ed.) (2006), *Action Plan for the conservation of sturgeons (Acipenseridae) in the Danube River Basin*, Nature and environment, No. 144.

Ciolac A. (2004), "Migration of fishes in Romania Danube river", *Applied Ecology and Environmental Research* 2(1): 155-159.

De Hagemeister J. (1835), *Mémoire sur le commerce des ports de la Nouvelle Russie, de la Moldavie et de la Valachie*, Odessa, Simphéropol.

De Marsigli L.F. (1744), *Description du Danube*, t. IV, Haga.

Giurescu C.C. (1964), *Istoria pescuitului şi a pisciculturii în România*, vol. I, Bucureşti.

Hensel K. and Holčik J. (1997), "Past and current status of sturgeons in the upper and middle Danube River", in *Sturgeon Biodiversity and Conservation*, pp. 185-200.

Holban M., Alexandrescu-Dersca Bulgaru M.M. (Eds.) (1973), *Călători străini despre Ţările Române*, Bucureşti, vol. V.

Luca C. (2007), *Ţările Române şi Veneţia în secolul al XVII-lea*, Bucureşti.

Manea G.I. (1980), *Sturionii. Biologie, sturionicultură şi amenajări sturionicole*, Bucureşti.

Musse R. (1935), "Les esturgeons de la mer Noire et leur pêche en Roumanie", *Annales de Géographie* 44, No. 248: 220-221.

Paraschiv M., Suciu R., and Suciu M. (2006), "Present state of sturgeon stocks in the Lower Danube, River, Romania", in *Proceedings of the 36th International Conference of IAD*, Austrian Committee Danube Research / IAD, Vienna, pp. 152-158.

Paul of Aleppo (1836), *The travels of Macarius, patriarch of Antioch,* vol. II, translated by F.C. Belfour, London.

Raymakers C. (2006), "CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora: its role in the conservation of *Acipenseriformes*", *Journal of Applied Ichthyology* 22: supplement 1, 53-65.

BIOLOGICAL RESPONSE OF THE CORALLINACEAE TO GLOBAL CLIMATE CHANGE AND HOW TO USE IT IN TEACHING AT MIDDLE SCHOOL

Fulvia Bradassi, Francesco Cumani, Guido Bressan
University of Trieste - Life Sciences Dept., Trieste (Italy)
e-mail: fulvia.bradassi@phd.units.it

Key-words: *carbon dioxide, ocean acidification, calcareous red algae, spores, school education, scientific knowledge and skills*

Abstract

The rising of atmospheric CO_2 partial pressure moves marine water pH onto a lower grade. Many marine organisms, that use $CaCO_3$ to build their skeletons, seem to be damaged by Ocean Acidification; especially shallow water ecosystems are at risk. A study on juvenile *thalli* of calcareous red algae was carried out in a microcosm experiment under different acidic conditions.
The encouraging preliminary result suggested taking the experience to educational system: a partnership with a middle school was established to fill the gap between research and school. An experimental course on global climate change and ocean acidification was offered to 14 years-old pupils. The course, experimentally based on calcareous red algae, represents not only a way to spread knowledge on global climatic change among the young people, but also a tool to measure how much new methods of teaching can improve scientific knowledge and skills at school level.

Introduction

According to International Panel on Climate Change last assessment report (IPCC, 2007), planet Earth is facing today a dramatic change in climate: data suggest that average temperature is increasing, both on land and in oceans, ice is melting, global ocean's currents circulation may change. These changes are taking place at a very quick rate.
At the same time partial pressure of atmospheric CO_2 has been rising in the last 200 years, reaching the level of 379 ppm in 2005, the highest value registered in the last 650.000 years, compared to CO_2 concentration derived from EPICA and Vostok Ice cores (IPCC, 2007).
It is widely accepted that there is a correlation between average temperature increase and atmospheric partial pressure of carbon dioxide increase. CO_2 overproduction is supposed to be caused mainly by human activities, i.e. by combustion of fossil fuels. IPCC models can reproduce actual temperature increase only if considering CO_2 as positive

forcing. The same models forecast a further increase in temperature, caused by a higher level of atmospheric carbon dioxide, whose intensity will depend on future CO_2 emission reduction policy (IPCC, 2007). By the end of this century, the concentration of CO_2 in the atmosphere is expected to rise to 780 ppm, which is about twice the present 379 ppm, and the CO_2 concentration in seawater will reach the same level (IPCC, 2007), if emissions would not be massively reduced in the meantime.

Global warming is probably not the only effect of the rise of atmospheric CO_2 partial pressure: continuous gas exchange between the air and seawater is predicted to lead to a rise in CO_2 concentrations at the ocean surface, since atmosphere and surface ocean exchange gases according to their partial pressure. Marine water is becoming more acidic because CO_2, when solved in water, reacts to form carbonic acid (H_2CO_3), which dissociates to bicarbonate (HCO_3^-) and carbonate ions (CO_3^{2-}), and protons (H^+). These reactions, summed under the term DIC (Dissolved Inorganic Carbon), allow water to store large amount of carbon dioxide, but, at the same time equilibriums turns to a lower pH value with less (CO_3^{2-}) carbonate ions and more (HCO_3^-) bicarbonate.

Ocean Acidification seems to be one of the most likely consequences of the increase of atmospheric CO_2 partial pressure, causing a remarkable change in marine environment (Hall-Spencer *et al.,* 2008). Ocean Acidification is already occurring and models forecast a further decrease in pH, reaching the level of 7.8 at the end of this century (Parry *et al.,* 2007).

$CaCO_3$ can deposit in different mineral forms: calcite, aragonite and high magnesium calcite, which have, in this progression, a higher solubility. Mineral deposition or dissolution take place according to saturation state of each of these minerals, which depends also on concentration, temperature and pressure (Saturation state: $\Omega = [Ca^{2+}][CO_3^{2-}]/Ksp$, where [X] means molar concentration of ions and Ksp is the solubility product). When Saturation state is higher than 1, mineral should deposit, when saturation state is lower than 1, it is supposed to solve (Kleypas *et al.,* 2005).

Many marine bioconstructors that use $CaCO_3$ to build their skeletons seem to be damaged by Ocean Acidification: biodeposition is reduced even at saturation state higher than one (Kleypas *et al.*, 2005).

Although Ocean Acidification might be of great impact on human activities, the phenomenon is still not well known and is almost unknown to the public.

The Case Study

Our research team is focussing on the biological response of calcareous red algae (Corallinaceae) to ocean acidification (Cumani *et al.*, 2008). The Corallinaceae play a fundamental ecological role in different marine ecosystems, from tropical reefs to high latitude cold waters. They can build even massive bioconstruction. Different evidence, supported by vast and recent literature, suggest that, depositing mainly high-Mg calcite into their cell-walls, the Corallinaceae may be more susceptible to ocean acidification than other calcifiers (Kuffner *et al.*, 2008).

During the last few years the effect of the increase of carbon dioxide was studied on mature calcareous red algae. Little currently is known on the effect of the marine acidification on the reproduction rates of the Corallinaceae (Jokiel *et al.*, 2008).

In May 2009 a study on the production and on the growth of Corallinaceae spores was realized in artificial controlled culture (microcosm) under different concentrations of carbon dioxide. The experiment was carried out in three different 20-liters tanks, allocated in a bigger one in order to control temperature. The first tank, containing natural sea water, was the control tank, at average pH value 8.2. CO_2 was bubbled in the second and in the third tank, in order to simulate future conditions. In the experiment's design first "control" bathtub (pCO_2 = 370 ppm and pH = 8.2) corresponds to contemporary conditions; second bathtub (pCO_2 = 550 ppm and pH = 8.0) simulates year 2050; third bathtub (pCO_2 = 760 ppm and pH = 7.8) corresponds to year 2100, following IPCC forecasts. This conditions were kept constant by a feed-back control: a pH-meter controlled an electronvalve, that activate or deactivate the CO_2 – insufflator (Figure 1).
The algae (encrusting red algae, such as *Lithophyllum* spp.) were collected and taken to the laboratory. These algae, called "mothers", released spores in the three tanks after higher temperature treatment (about 25°C for 2 hours). The spores were collected on microscopy slides. The development of the spores was monitorized under different conditions, taking notice of qualitative and quantitative features (Figure 2).
A census of *thalli* was ended within the first week of culture: 604 *thalli* were counted in tank 82, 168 *thalli* in tank 80, and 235 in tank 78. After 5 week were present 243 *thalli* in tank 82 (mortality 59.77%), 59 in tank 80 (mortality 64.86%) and 74 *thalli* in tank 78 (mortality 68.52) (Figure 3).

Laboratory

Ph: F. Cumani

3 pH-meters control electronvalves that activate or deactivate CO_2 insufflators in order to keep pH at fixed value

Three 20 Liters tanks, allocated in a bigger one, in order to control temperature.

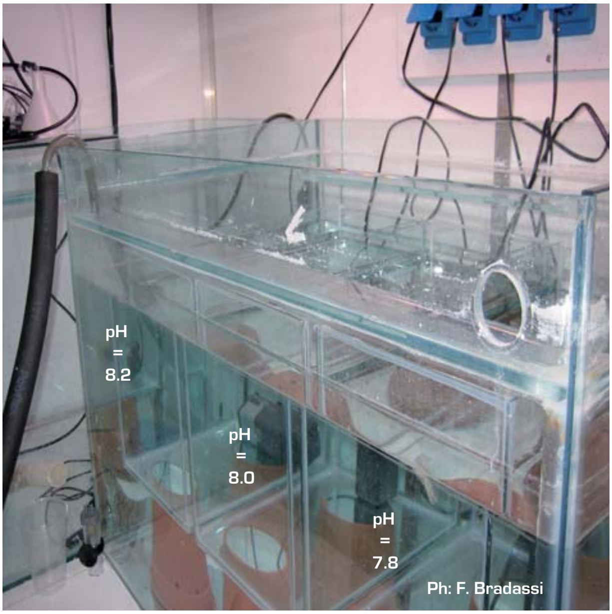


Figure 1. Microcosm.

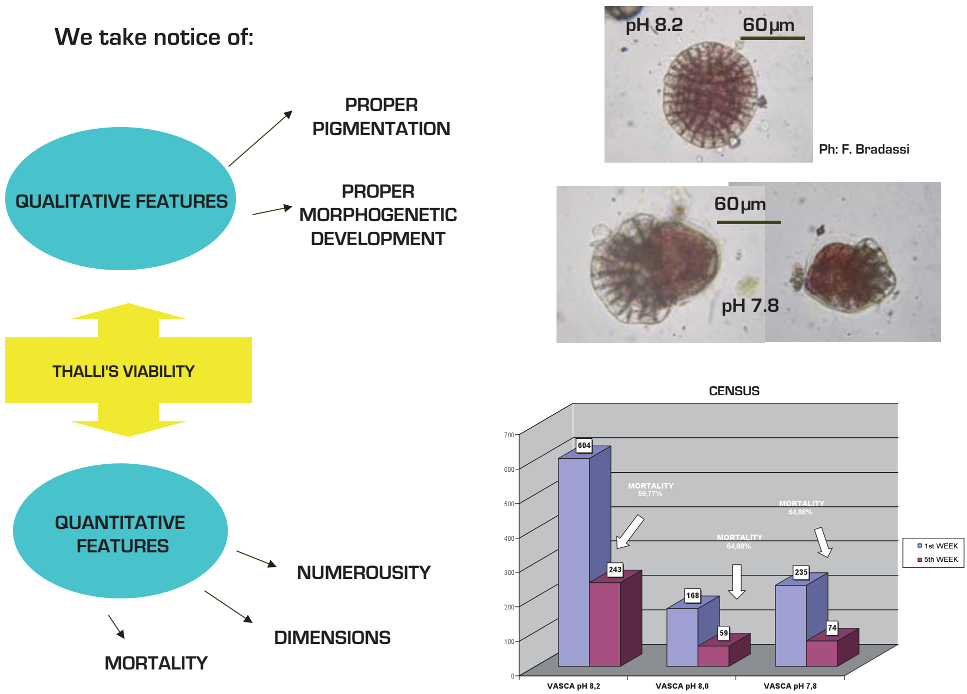


Figure 2. Monitoring of spores' development.

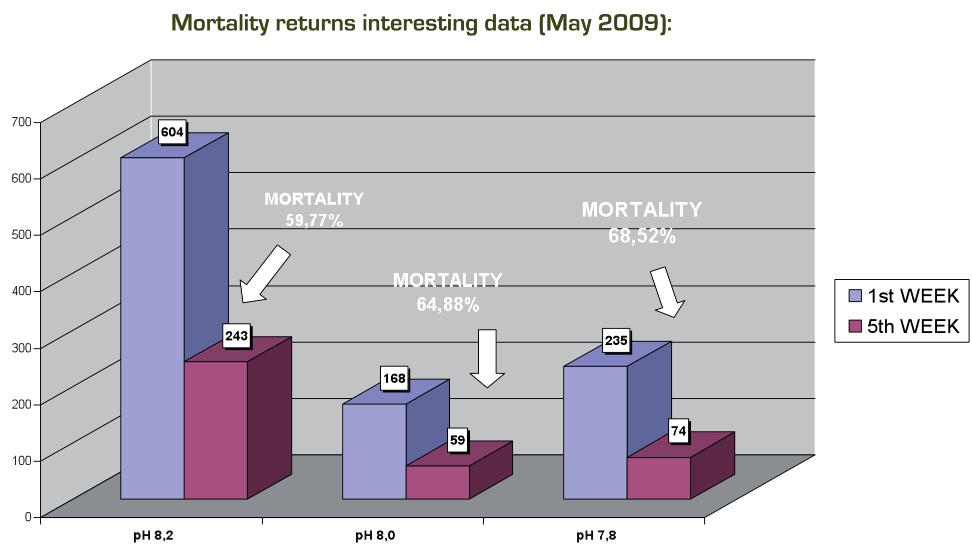


Figure 3. Spore production and mortality at different pH value treatments.

Considering qualitative features, it was noticed that many spores in tank 78 did not follow a proper morphogenetic development in all directions, leaving some sectors undeveloped (Figure 2).
This preliminary result, to be confirmed by further research, seems therefore to suggest that the increasing of CO_2 concentration in artificial culture causes an inhibition of the Corallinaceae spore production, an increase of the germination disks mortality and an inhibition of spores' development.

School experiment

Since education and knowledge is the only way to change habits of new generation, regarding anthropic CO_2 emission and ocean acidification prevention, it has been decided to build a link between researchers and school.
Thanks to specific skills in teaching that some members of the group developed for previous working experiences, and thanks to the support of C.I.R.D. (Interdepartmental Centre for Didactic Research – University of Trieste), a partnership with a middle school in town was established. An experimental course on global climate change and ocean acidification was offered to 14 years-old pupils. The experiment, based on *thalli* of *Lithophyllum incrustans,* demonstrates that a lower pH than actual (7.8 versus 8.2) influences the growing rate and even the morphogenetic development of microscopic *thalli*.
A group of 21 students was randomly chosen from all the 3rd classes of the school and was offered to join the project, attending a course of 25 hours. Another group of 21 students, not taking part in lessons, represented the control group.
The course was based on experimental observation of the growing of microscopic *thalli*, from spores release in the 1st day of culture until 14th day. The pupils learned to treat two 20 litres marine aquariums in which they grow the algae. In the first tank the pH value was the natural one (8.2) while in the second, the pH value was... maintained lower (7.8) through CO_2 insufflations. Pupils also learned to use instruments, to collect qualitative and numerical data, to represent the data, to elaborate them, and to take conclusion from the outcoming.

Ending notes

The personal engagement of the students, achieved through self-motivation, plays a fundamental role into the learning process: it is supposed that the girls and boys, attending to this course, should develop their scientific knowledge and skills, including scientific language, more than control group (Randler and Bogner, 2009)
All the students have been tested at the beginning of the school year, and will be at the end, to estimate previous skills and knowledge and homogeneity between the two tested groups.
The scientific abilities and knowledge taken as terms of reference are those fixed by OCSE – PISA (*Organizzazione per la Cooperazione e Sviluppo Economico* - Programme International Student Assessment) for 14 years old students.
The OCSE standard (OCSE, 2007) is compared to the Italian ministerial standard (Ministero della Pubblica Istruzione, 2007), recently revised and updated.

Bibliography

Cumani F., Di Pascoli A., and Bressan G. (2008). Osservazioni fenoecotipiche di bioindicatori in coltura di laboratorio *Pneophyllum fragile* Kützing e *Hydrolithon boreale* (Foslie) Chamberlain (Corallinales, Rhodophyta). Biologia Marina Mediterranea 15(1): 260-261.

Hall-Spencer J.M., Rodolfo-Metalpa R., Martin S., Ransome E., Fine M., Turner S.M., Rowley S.J., Tedesco D., and Buia M.C. (2008). Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature 454: 96-99.

Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K., and Johnson C.A. (Eds.) (2001). Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 881 pp.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri R.K, and Reisinger A. (Eds.). IPCC, Geneva, Switzerland. 104 pp.

Jokiel P.L., Rodgers K.S., Kuffner I.B., Andersson A.J., Cox E.F., and Mackenzie F.T. (2008). Ocean acidification and calcifying reef organisms: a mesocosm investigation. Coral Reefs 27: 473–483.

Kleypas J.A., Feely R.A., Fabry V.J., Langdon C., Sabine C.L., Robbins L.L. (2005). Impacts of ocean acidification on coral reefs and other marine calcifiers: A guide for future research. Report of a workshop held 18-20 April 2005, St. Petersburg, FL, sponsored by NSF, NOAA, and the U.S. Geological Survey. 88 pp.

Kuffner I.B., Andersson A.J., Jokiel P.L., Rodgers K.S., and Mackenzie F.T. (2008). Decreased abundance of crustose coralline algae due to ocean acidification. Nature Geoscience 1: 114-117.

Ministero della Pubblica Istruzione (2007). Indicazioni per il curricolo per la scuola dell'infanzia e per il primo ciclo d'istruzione. Ed. Ministero Pubblica Istruzione (Roma). 111 pp.

OCSE (2007). Valutare le competenze in scienze, lettura e matematica. Quadro di riferimento di PISA 2006. Roma, Armando ed. pp. 11-22; pp. 25-54; pp.135-198.

Parry M., Canziani O., Palutikof J., van der Linden P., and Hanson C. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press.

Randler C., and Bogner F.X. (2009). Efficacy of two different instructional methods involving complex ecological content. International Journal of Science and Mathematics Education 7: 315-337.

FISHERY IN THE NORTHERN ADRIATIC SEA FROM THE SERENISSIMA FALL TO PRESENT: AN HISTORICAL AND ECOLOGICAL PERSPECTIVE

Tomaso Fortibuoni
ISPRA - Italian National Institute for Environmental Protection and Research, Chioggia (Italy)
OGS - National Institute of Oceanography and Experimental Geophysics, Trieste (Italy)
e-mail: tomaso.fortibuoni@isprambiente.it

Key-words: *environmental history, naturalists, landing statistics, fish community structure indicators*

Abstract

In the marine realm fishery has been described as the major driving force altering fish communities. Moreover, fishery chronologically precedes all other human sources of disturbance, such as pollution, eutrophication and anthropogenic climate change. Marine ecosystems have been severely altered centuries ago, while management policies of marine resources are in most cases based exclusively on recent (few decades) observations. This could lead to the underestimation of ecosystems productive capacity and species biodiversity, the well known “shifting baseline syndrome”. Therefore, the recovery and analysis of historical data is now at the forefront of fishery science, which is trying to reconsider past baselines to better understand ecosystems dynamics and to set targets for restoration and management. This is the main task of the global project History of Marine Animal Populations (HMAP), in whose context this study was developed. The challenge when studying long-term trajectories of marine species is the collection and analysis of proxy data, since qualitative information on the past abundance of marine organisms is common in many areas, while *ad hoc* quantitative data are lacking. In this framework the Northern Adriatic Sea is a valuable case study, due to the abundance of historical sources on fish fauna and fishing activities and due to its ecological value, which derives from the high primary and secondary productivity that makes it one of the most exploited Mediterranean basins. This paper aims at briefly describing the development of fishing capacity between 1800 and 2000 in the area and studying long-term (2 centuries) changes in fish community through naturalists’ descriptions of marine fauna and landing statistics. An increase in the number of fishing boats and fishermen characterized the period between the second half of the 19th century and the 1st World War. A real revolution of fishing activities occurred after the 2nd World War, with the introduction of the engine propeller and other technological devices, as for instance the acoustic fish finders or the synthetic fibres. The intercalibration and integration of naturalists’ descriptions of fish fauna and landings allowed constructing a semi-quantitative 2 centuries time-series of species “perceived abundance”. Temporal trends of fish community structure indicators highlighted the presence of a long-term “fishing down” process. Chondrichthyes, big demersal and late-maturing species relative biomass, in fact, significantly declined, indicating the presence of long-term changes in the structure of the fish community.

Introduction

Most marine ecosystems are deeply different from their pristine state (Jackson *et al.*, 2001; Pinnegar *et al.*, 2002; Lotze and Milewski, 2004; Lotze, 2005; Rosenberg *et al.*, 2005; Sáez-Arroyo *et al.*, 2005; Lotze *et al.*, 2006; Ainsworth *et al.*, 2008). Profound historical changes of marine assemblages are considered to be the result of the interactions between natural fluctuations and human-induced modifications, where fishery has been recognized as the main driving force (Jackson *et al.*, 2001; Pinnegar and Engelhard, 2008). Environmental history can play a major role in the process of setting a clear baseline of what lived in the oceans and of defining which driving forces (either natural or anthropogenic) contributed to shape the actual state of marine living resources. Studying historical records of ecological systems to reconstruct the pristine state of resources is a fundamental prerequisite to set management goals for sustainability and restoration. Thus, the rescue and integration of historic data, that encompass archival, anthropological and scientific sources, represent a real opportunity for describing patterns of exploitation of marine resources and defining the abundance of marine species in the past. In this context, the use of proxy data seems unavoidable (Palomares *et al.*, 2006; Anderson, 2006). Indeed, since in most cases the available quantitative data on marine populations date back just to the second half of the 20th century (Jackson *et al.*, 2001), former descriptions of marine fauna are usually anecdotal. This is particularly true in the Mediterranean region, where monitoring programs for assessing the status of marine resources cover at most the last 30 years, failing to encompass the life-spans of many species and the time scale of many natural and human-induced phenomena (Margalef, 1985).
In this framework the Adriatic region represents a promising case-study for marine environmental history, due to the abundance of historic sources on fishing fleets operating in the area, descriptions of fish fauna provided by naturalists since the begin of the 19th century, and statistical records of landings that date back to the end of the 19th century. The Adriatic region has been inhabited and subjected to human action for millennia (fishery, pollution, eutrophication, habitat degradation), thus its present status is the result of the long-term actions of people inhabiting its coastal areas. Moreover, the Northern Adriatic Sea is historically one of the most exploited Italian basins (Botter *et al.*, 2006), due to the high primary and secondary production which sustain a high fishery productivity (Bombace *et al.*, 2002).
The main objectives of this paper were to describe the development of fishing capacity between 1800 and 2000 in the Northern Adriatic Sea and to study long-term (2 centuries) changes in fish community through naturalists’ accounts and landing statistics. For the purpose, an extensive survey was carried out between January 2007 and March 2008 in libraries and archives of Venice, Padua, Rome, Trieste, Chioggia (Italy) and Split

(Croatia) to collect reports, books and scientific publications dealing with fishery and fish fauna in the Northern Adriatic Sea. Approximately 500 documents were examined, of which around 300 were acquired. Such documents include both scientific and humanistic sources, such as naturalists' descriptions of fish fauna, grey literature dealing with fishing activities in the study-area, landing statistics and official governmental reports on fishery and fishing fleets.

FISHING ACTIVITIES

In the 19th century, fishing activities developed differently between the eastern and the western sides of the Adriatic, according to the characteristics of the coastal areas. The eastern coast is, in fact, hilly and has predominantly rocky shore, considerable sea depths and lot of islands, while the western coast is characterized by a sedimentary shoreline with a system of deltas and lagoons, low and sandy shores and shallow waters. Differences in fishing activities were also a consequence of the diverse attitude of fishermen belonging to the Austro-Hungarian Empire (eastern coast) and the Reign of Italy (western coast). The former, in fact, were manly involved in coastal fishery while the latter in "open sea" fishery.
On the eastern coast, before the industrialization of fishery, it was possible to roughly distinguish three different ways of exploiting marine resources: coastal fishery and seasonal fishery, mainly practised by local inhabitants, and "open sea" fishery, practised almost exclusively by the Italians (principally fishermen coming from Chioggia, an island near Venice, called *Chioggiotti*). Coastal fishery was practised with a wide variety of highly specialized artisanal fishing gears (trammel-nets, seines, drift-nets, etc.), that were in most cases mono-specific (conceived to exploit one or few species). It was practiced close to the shore with small boats, and it gave low yields, but usually quite high earnings, since it targeted valuable species, such as the European sea-bass and the Norway lobster. It represented, for the inhabitants of the coastal areas, an integration to other activities (agriculture, farming, industry), and it was mainly a subsistence activity. The most important seasonal activities targeted migratory species, such as sardines, anchovies, mackerels and tunas. Tuna fishing was one of the most profitable activities along the eastern coast, where different kind of tuna-traps were located along the shore, mainly in the Dalmatian region. It was practised during the season when tunas approach the coast (August-October), following the small pelagic shoals, by means of fixed nets. Most important targeted species were the Northern blufin tuna (*Thunnus thynnus*), the Little tunny (*Euthynnus alletteratus*) and the Atlantic bonito (*Sarda sarda*).
"Open sea" fishery was mainly practised by fishermen from Chioggia, called the *Chioggiotti*. The *Chioggiotti* used to exploit wide areas of the Adriatic, moving between the two coasts following species migrations. "Open sea" fishery was practised with towed gears (e.g., *cocchia*, *tartana*, *ostregher*) targeting demersal species.
From the second half of the 19th century till the I World War on both sides of the Adriatic the number of fishermen and of fishing boats increased (Figure 1), but substantial changes in technologies and gears were not introduced.

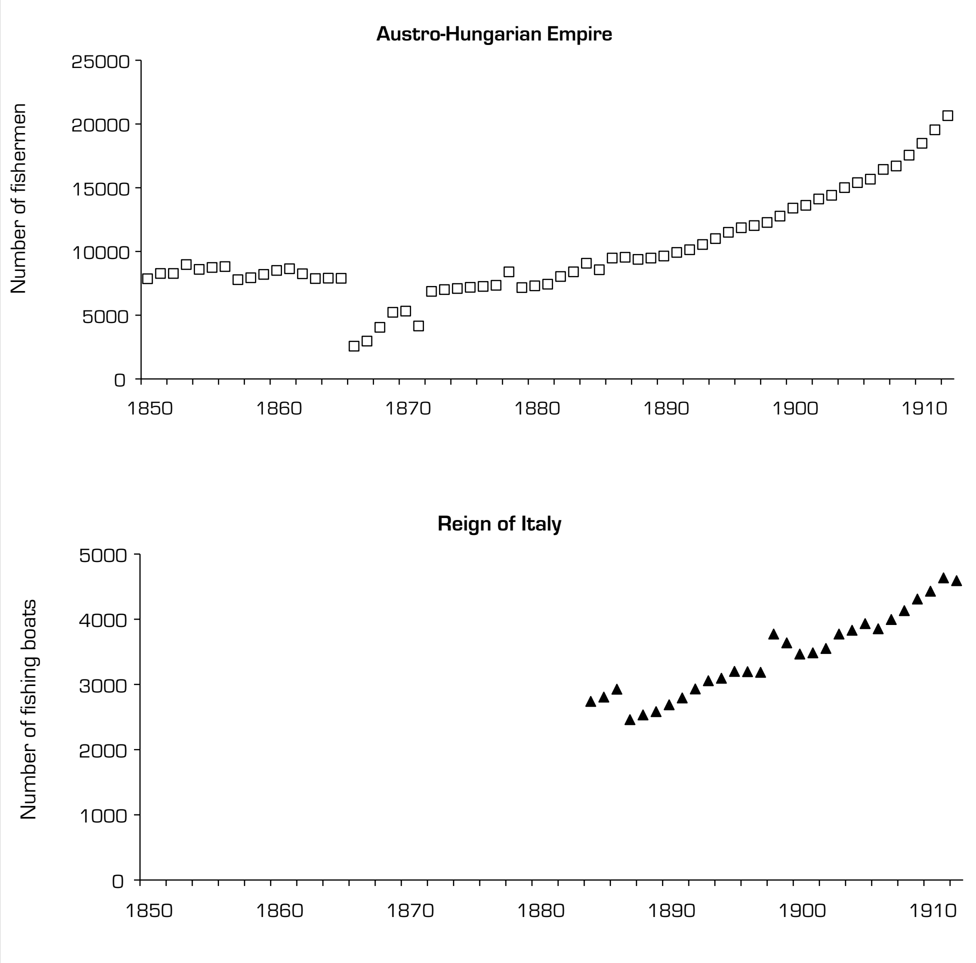


Figure 1. Number of fishermen in the Austro-Hungarian Empire (a) and number of fishing boats in the Reign of Italy (b) between 1850 and 1912. In the Austro-Hungarian Empire in the period 1850-1866 the number of fishermen substantially did not change and fishery was a subsistence activity; in 1866 it decreased as a consequence of the annexation of Venice to the Reign of Italy, while since 1880 it began to rapidly increase. Unfortunately no data are available before 1884 for the Reign of Italy, while in the following years the number of fishing boats sharply increased.

Between the 1st and the 2nd World Wars, fishing fleets operating in the Adriatic underwent significant technological improvements, first of all the introduction of the engine propeller that gradually substituted the sail. After the 2nd World War, the number of fishing vessels operating in the Adriatic sharply increased until the 80s. Then, in some marine compartments, it slightly declined, maybe as a consequence of the decline of most important commercial stocks and of policies intended to reduce the fishing capacity of fishing fleets operating in the area. The motorization of fishing vessels allowed to move faster and further from the coast and to operate also during bad weather (or in absence of wind), thus improving the number of days at sea. The wide variety of artisanal mono-specific fishing gears was substituted with multi-specific, more efficient (and more impacting) fishing gears: in the 40s the *saccaleva* (purse seine), targeting pelagic fish; in the 60s the *rapido* (beam trawl), targeting demersal fish and the *volante* (pair midwater trawl), targeting small pelagic fish; finally, in the 70s the *draga idraulica* (dredge), targeting bivalves and demersal fish. The engine propeller and the new technologies (radar, sonar, fax, freezers, GPS, ecosounder, synthetic fibres, etc.) introduced dramatically improved the fishing capacity of the Adriatic fleets, and improved technology for long masked serial depletions. In Figure 2 the development of the fishing capacity in the Northern Adriatic Sea in the last two centuries is summarized.

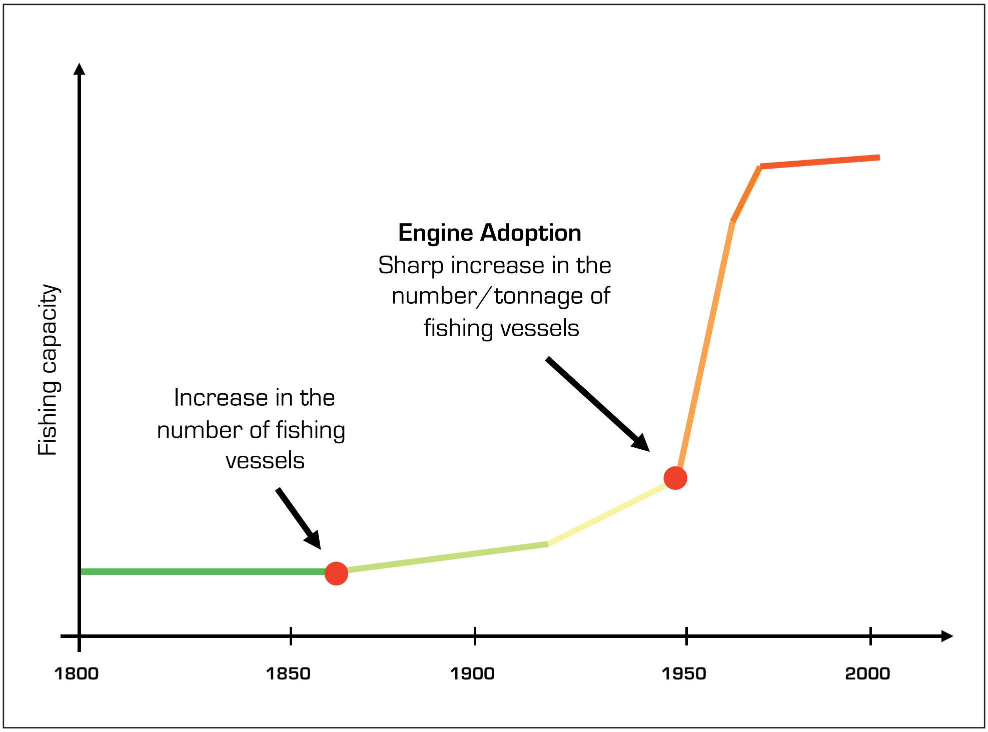


Figure 2. Schematic representation of the development of the fishing capacity in the Northern Adriatic Sea in the last two centuries. Till the second half of the 19th century, it substantially did not change, while at the end of the century the number of fishing vessels/fishermen began to increase rapidly. Great changes occurred after the II World War, when the adoption of the engine propeller, the introduction of new and more efficient fishing gears and of new technologies, dramatically improved the fishing capacity of the fishing fleets operating in the Adriatic. In the last decades the fishing capacity almost stabilized, as a consequence of national and European policies and as a consequence of the severe depletion of most commercial stocks.

What about fish populations

The main problem, when trying to describe fish population changes on the long-term, is the lack of quantitative data. Most resource monitoring programs, in fact, date back only to the last decades. This is true also for the Adriatic Sea, therefore the main source of information on fish populations in the 19th century is the historical records of Italian and Austro-Hungarian naturalists. These documents, particularly abundant in the 19th century following the ascendancy of the Linnaean system (Edmonds, 2005), contain species lists, descriptions of their "perceived abundance" and insights on their main ecological characteristics (distribution, size, habitat, migrations). A database was compiled with the information on fish species reported by 36 naturalists, covering a period of about 150 years (1818-1956). Naturalists' knowledge of fish fauna was based mainly on direct observations at fish markets and at ports, on interviews to fishermen, on literature and on the analysis of Natural Museums Collections.

Species synonymies were updated according to the modern nomenclature, by comparing old scientific names to global species databases (Froese and Pauly, 2009) and modern taxonomy books (Tortonese, 1956, 1970, 1975). In these reports 394 fish species were described in terms of presence/absence, abundance, habitat preferences, seasonality, size, etc. Species lists were checked, and about 139 fish species were excluded from the database, i.e. in case of i) species belonging to freshwater habitats; ii) exotic species cited in the documents but probably misreported (e.g., the Atlantic cod *Gadus morhua*, reported by an author in 1822); iii) erroneous names and species that do not exist (e.g., *Laeviraja morula* or *Notidanus barbarus*); iv) species cited by less than 5 authors. Each observation was ranked, according to naturalists' "perceived abundance" descriptions, using a 4-level scale coding system (i.e., "very rare", "rare", "common", "very common"). Coding was based on naturalists' descriptions of fish species: for instance, if a species was described as "found accidentally" or "occasionally" it was coded as "very rare". Information were arranged chronologically and subdivided into periods of 25 years.

To study temporal trends, it was necessary to quantify classes of "perceived abundance". Since naturalists based their evaluation on species abundance by observing catches at fish markets and ports, we collected landing statistics to intercalibrate these two sources of information. Landing statistics were referred to major fish markets or to wide coastal areas of the Northern Adriatic Sea, for which landing logbooks were established by the authority ruling in the relative period. These sources referred to Venice, Chioggia, Trieste (Italy), Rijeka (Croatia) and the Austro-Hungarian littoral, and they cover the period between 1874 and 2000. These fish markets were historically the most important of the Northern Adriatic Sea (Faber, 1883; Levi Morenos, 1916; D'Ancona, 1926, 1949), and fleets supplying the markets were used to exploit large areas of the Adriatic Sea (Botter *et al.*, 2006). Annual landings were given for each species/group of species in terms of wet weight (kg/year). Being biased toward commercial species and not standardized in terms of fishing effort and fishing gear, landings have the intrinsic limitations of fishery-dependent data, however, they are useful to give indications on changes in the composition of exploited fish communities by means of landings proportions. Thus, landings were expressed as the percentage proportion of each species in the total catch, and data were averaged over periods of 25 years to make them comparable with naturalists' information.

We used periods with overlapping information (1875-1900, 1901-1925 and 1926-1950) to intercalibrate the two databases and quantify, by defining a set of numerical weights, classes of "perceived abundance". The procedure (Fortibuoni *et al.*, 2008) allowed integrating the two databases into a semi-quantitative description of fish species abundance over a period of two centuries (1800-2000) (Figure 3).

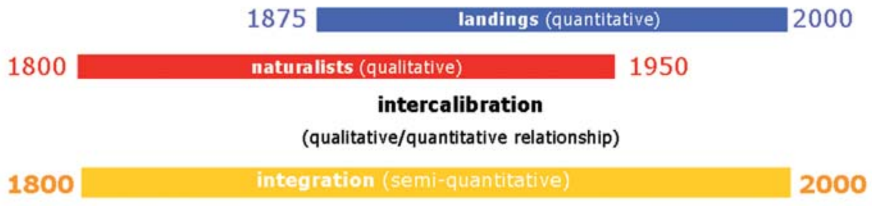


Figure 3. Conceptual model of the intercalibration and integration methodology that allowed to put naturalists' qualitative descriptions of fish "perceived abundance" into a quantitative framework. The intercalibration allowed associating to naturalists' classes of "perceived abundance" a set of numerical weights based on landings proportions. Furthermore, it allowed to define class limits to convert landings for the periods 1951-1975 and 1976-2000 (for which naturalists' descriptions were not available) into classes of "perceived abundance". This resulted in the description of species "perceived abundance" with the same semi-quantitative metric over e period of two centuries (1800-2000).

A set of fish community structure indicators, based on species trophic level, maximum body length and age at first maturity, were defined to study long-term changes in fish community composition. A negative trend of the relative biomass of large demersals, large-sized species, late-maturing species and of Chondrichthyes (sharks, skates and rays) was evident. This result reflects the fact that large fish species are usually more vulnerable to a wide variety of fishing gears, are more valuable and thus exploited intensively since ancient time (Fromentin, 2003). Furthermore, these species have correlated life-history traits (e.g., late maturity, low population growth rates) that make them less resilient to exploitation (Pauly *et al.*, 1998; Jennings *et al.*, 1999; Dulvy *et al.*, 2004).

Conclusions

Results reported in this paper highlight the importance of integrating different kind of information to reconstruct long-term changes of fish communities. Naturalists' eye-witness accounts proved to be a useful tool to describe fish abundance and diversity in the past, which is relevant in the fishery management context since these sources have been for a long time disregarded by fishery biologists as being "anecdotal" and not "science" (Mackinson, 2001). The methodology we applied allowed the integration of different kind of data, i.e. qualitative and quantitative data. This enabled to extend analysis on fish community structure changes from the beginning of the 19th century to the end of the 20th century using the same metric. Indications of a "fishing down" process (Pauly et *al.*, 1998) in the Northern Adriatic Sea seem realistic, but further investigations are required to obtain more robust conclusions. Nevertheless, results are in agreement with observations by other authors in the Northern Adriatic Sea (Coll *et al.*, 2006; 2008) and in other areas characterized by high fishing pressure (for some examples consider Jennings *et al.*, 1999; Jackson *et al.*, 2001; Lotze *et al.*, 2006; Ainsworth *at al.*, 2008). Moreover, we know from historical literature that already at the end of the 19th century first signs of depletion of marine resources were evident in the Adriatic Sea (Sennebogen, 1897). Fishery, even though not yet industrialized, was considered responsible for structural changes in fish communities, as hypothesized by the fishery biologist Umberto D'Ancona (1926, 1949). In particular, D'Ancona noticed that after the two World Wars, during which fishing effort was sharply reduced or even stopped, an increase in yields was observed, and the frequency in landings of some species changed remarkably, in particular the percentage of Chondrichthyes increased. The Adriatic region has been characterized by intense fishing, at least from the second half of the 19th century (Botter *et al.*, 2006), but the fishing capacity, effort and consequently impact have sharply increased after the II World War with the industrialization of fishery. It is clear that fish community structure has changed and that fishery has played a major role, but a sound analysis of the role played by different driving forces (both anthropogenic and natural) needs further analysis.

Bibliography

Ainsworth C.H., Pitcher T.J., and Rotinsulu C. (2008). Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia. Biological Conservation 141: 848-859.

Anderson K. (2006). Does history count? Endeavour 30(4): 150-155.

Bombace G. (2002). Remarks on the fishing, biodiversity and marine protected areas. Biologia Marina Mediterranea 9(1): 48-70.

Botter L., Giovanardi O., and Raicevich S. (2006). Chioggia's fishing fleet migration in the Adriatic Sea between the 19th and the early 20th centuries. Journal of Mediterranean Studies 16(1/2): 27-44.

Coll M., Santojanni A., Palomera I., Tudela S., and Arneri E. (2006). An ecological model of the Northern and Central Adriatic Sea: analysis of ecosystem structure and fishing impact. Journal of Marine Systems 67: 119-154.

Coll M., Lotze H.K., and Romanuk T.N. (2008). Structural degradation in Mediterranean Sea food webs: testing ecological hypotheses using stochastic and mass-balance modelling. Ecosystems 11: 939–960.

D'Ancona U. (1926). Dell'influenza della stasi peschereccia del periodo 1914-18 sul patrimonio ittico dell'Alto Adriatico. Memorie del Regio Comitato Talassografico Italiano CXXVI: 5-91.

D'Ancona U. (1949). Rilievi statistici sulla pesca nell'Alto Adriatico. Atti dell'Istituto Veneto di Scienze, Lettere ed Arti CVIII: 41-53.

Dulvy N.K., Ellis J.R., Goodwin N.B., Grant A., Reynolds J.D., and Jennings S. (2004). Methods of assessing extinction risk in marine fishes. Fish and Fisheries 5: 255-276.

Edmonds M. (2005). The pleasures and pitfalls of written records. In The historical ecology handbook, Egan D., and Howell E. (Eds.). E.A. Society for Ecological Restoration International (Washington DC). pp. 73-100.

Faber G.L. (1883). The fish markets. In The fisheries in the Adriatic and the fish thereof. Bernard Ouaritch (London). pp. 141-147.

Fortibuoni T., Giovanardi O., Libralato S., Raicevich S., and Solidoro C. (2008). Integrating historical naturalists' descriptions and statistical-scientific data to describe changes in fish assemblages over the last two centuries in the Northern Adriatic Sea (Mediterranean). ICES CM 2008/R:14.

Froese R., and Pauly D. Editors. FishBase. World Wide Web electronic publication. www.fishbase.org (2009).

Fromentin J.M. (2003). The East Atlantic and Mediterranean bluefin tuna stock management: uncertainties and alternatives. Scientia Marina 67: 51-62.

Jackson J.B.C., Kirby M.X., Berger W.H., Bjorndal K.A., Botsford L.W., Bourque B.J., Bradbury R.H., Cooke R., Erlandson J., Estes J.A., Hughes T.P., Kidwell S., Lange C.B., Lenihan H.S., Pando J.M., Peterson C.H., Steneck R.S., Tegner M.J., and Warner R.R. (2001). Historical overfishing and the recent collapse of coastal ecosystems. Science 293(5530): 629-37.

Jennings S., Greenstreet S.P.R., and Reynolds J.D. (1999). Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. Journal of Animal Ecology 68: 617-627.

Levi Morenos D. (1916). L'emigrazione peschereccia pel lavoro nell'Adriatico. In Memoria XXXII del Regio Comitato Talassografico Italiano. Ed. Premiate Officine Grafiche di Carlo Ferrari (Venice). pp. 9-143.

Lotze H.K., and Milewski I. (2004). Two centuries of multiple human impacts and successive changes in a North Atlantic food web. Ecological Applications 14(5): 1428–1447.

Lotze H.K. (2005). Radical changes in the Wadden Sea fauna and flora over the last 2000 years. Helgoland Marine Research 59: 71-83.

Lotze H.K., Lenihan H.S., Bourque B.J., Bradbury R.H., Cooke R.G., Kay M.C., Kidwell S.M., Kirby M.X., Peterson C.H., and Jackson J.B.C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312: 1806-1808.

Mackinson S. (2001). Integrating local and scientific knowledge: an example in fisheries science. Environmental Management 27(4): 533-545.

Sennebogen E. (1897). Della pesca nell'Adriatico in generale e su quella nella Dalmazia in particolare. Neptunia 12(9-10): 137-149.

Pinnegar J.K., Jennings S., O'Brien C.M., and Polunin N.V.C. (2002). Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. Journal of Applied Ecology 39: 377-390.

Rosenberg A.A., Bolster W.J., Alexander K.E., Leavenworth W.B., Cooper A.B., and McKenzie M.G. (2005). The history of ocean resources: modelling cod biomass using historical records. Frontiers in Ecology and the Environment 3(2): 84-90.

Saez-Arroyo A., Roberts C.M., Torre J., and Carino-Olvera M. (2005). Using fishers' anecdotes, naturalists' observations and grey literature to reassess marine species risk: the case of the Gulf grouper in the Gulf of California, Mexico. Fish and Fisheries 6: 121-133.

PINNEGAR J.K., AND ENGELHARD G.H. (2008). The 'shifting baseline' phenomenon: a global perspective. Reviews in Fish Biology and Fisheries 18: 1-16.

PALOMARES M.D.L., MOHAMMED E., AND PAULY D. (2006). On European expeditions as a source of historic abundance data on marine organisms: a case study of the Falkland Islands. Environmental History 11: 835-847.

PAULY D., CHRISTENSEN V., DALSGAARD J., FROESE R., AND TORRES Jr. F. (1998). Fishing down marine food webs. Science 279: 860-863.

MARGALEF R. (1985). Introduction to the Mediterranean. In Key Environments: Western Mediterranean, Margalef R. (Ed.). Pergamon Press (Oxford). pp. 1-163.

TORTONESE E. (1956). Leptocardia, Ciclostomata, Selachii. Fauna d'Italia (Vol II). Ed. Calderini (Bologna). 334 pp.

TORTONESE E. (1970). Osteichthyes (Pesci Ossei: Parte Prima). Fauna d'Italia (Vol X). Ed. Calderini (Bologna). 540 pp.

TORTONESE E. (1975). Osteichthyes (Pesci Ossei: Parte seconda). Fauna d'Italia (Vol XI). Ed. Calderini (Bologna). 636 pp.

AN OVERVIEW OF ERITREAN FISHERY: PAST AND PRESENT (1950-2010)

Tsegay Fessehaye Kassa
National Fisheries Corporation, Fishing Enterprise, Massawa (Eritrea)
e-mail: tsegayf@gmail.com

Key-words: *Eritrea, fisheries, Red Sea, catches, resources, policy, history*

ABSTRACT

This report examines some past and present features of fishery in Eritrea from the 1950s onwards. It was developed from available literature, fishery experiences and data of the National Fisheries Corporation as well as of the Ministry of Marine Resources of Eritrea.

Eritrean marine fisheries were very active, being historically carried out at a subsistence level using canoes and small plank boats under sail and oar since 1950s, followed by an increasing number of motorized boats in 1960. The development of the Eritrean fishery sector was affected by the political changes that occurred in the Country; in particular, the warfare before the establishment of Eritrea (1993) determined a reduction in fishing activities and landings. Since then, fishery started to be revitalized through the building of new or the renovation of old infrastructures, resulting in the expansion of both artisanal and industrial fisheries in the area. As a result, catches started to grow, largely dominated by industrial catches, particularly in 1999. Since the Eritrean Red Sea is characterized by high biodiversity and precious habitats, in particular coral reefs, fishery exploitation must be controlled in order to ensure the sustainable long-term use of marine resources.

INTRODUCTION

Eritrea is a small country located in the North East Africa, with a total surface of 124320 km^2 (including the Dahlak Archipelago) and a population of about 4.5 million people; the Country officially celebrated its independence from Ethiopia on May 24, 1993. The Eritrean coastline, located along the South Western side of the Red Sea[1], stretches from its northern border with Sudan at Ras Kesar to its southern border with Djibouti at Ras

1 Red Sea is a direct translation from the Greek *Erythra Thalassa*, Arabic *Al-Baḥr Al-Aḥmar* (البحر الأحمر), and Tigrinya *Qeyḥ bāḥrī*. The name of the sea doesn't indicate the color of the water but may be referred to the blooms of the red-colored Cyanobacteria *Trichodesmium erythraeum* occurring seasonally near the water surface.

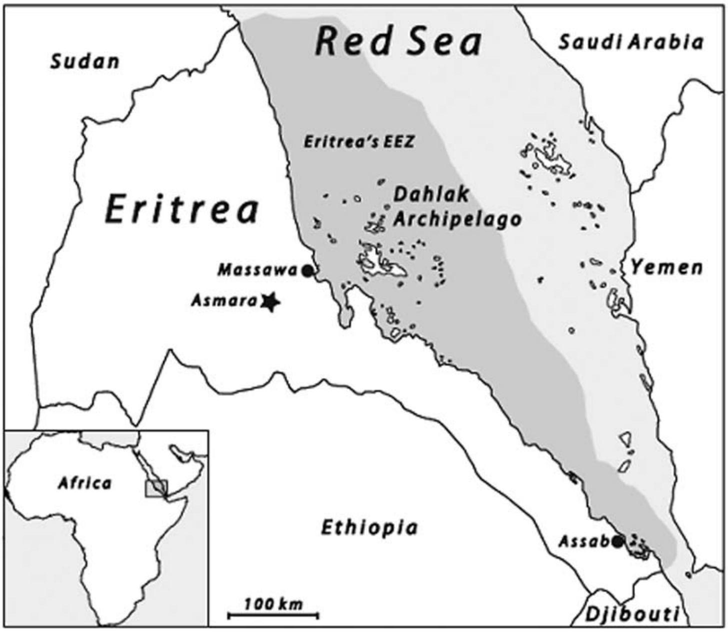


Figure 1. Map of Eritrea showing the Economic Exclusive Zone (EEZ, dark grey), the islands of the Dahlak Archipelago and the main Eritrean fishing harbors of Massawa and Assab.

Dumera (Figure 1). It is 3300 km long (1350 km along the mainland and 1950 km belonging to 354 islands and islets). Eritrea's territorial waters extend over 12 nautical miles (about 22 km) from mainland and islands coastline, with a total area of 55000 km^2. Moreover, the Eritrea's Exclusive Economic Zone (EEZ, extending up to 200 nautical miles from the mainland, thus including the territorial waters) is estimated to be 120000 km^2 (Source: ECMIB GIS Unit 2007).

Climate and oceanography

Eritrea's highlands are the highest territory of the area and, therefore, have a much cooler and damper weather than the semi-arid coast along the Red Sea and the western hills and lowlands. The average temperature in Asmara is 16°C, whereas in Massawa (on the coast) it is 30°C and can reach 50°C. Average rainfall in Asmara is 508 millimeters per year, while in Massawa it is only 205 millimeters per year. The Red Sea coastal plains of Eritrea are characterized by rocky deserts and sand dunes, very high temperatures, annual evapotranspiration of 2000 mm and annual rainfall of less than 200 mm. The Red Sea is one of the most saline water bodies in the world (salinity ranges between 36 and 38‰), due to the effects of water circulation pattern, resulting from evaporation and wind stress. Winter mean sea level is 0.5 m higher than in summer. Tidal speed through constrictions, caused by reefs, sand bars and low islands, commonly exceeds 1-2 m*s-1 and, usually, the tidal range is higher in the Northern Eritrean Red Sea than in its Southern counterpart, being comprised between 1.5 m and 0.97 m in Massawa and Assab areas, respectively.

Coastal and marine habitats

The Eritrean Red Sea is a rich and diverse ecosystem and its continental shelf is the largest of all the countries along the Red Sea. The shelf around the Dahlak Archipelago, where most of the coral reefs concentrate, represents about the 25% of the Eritrea's total continental shelf; the 19% of the shelf is less than 30 m deep, and thus off limits to trawling activities (Guidicelli, 1984). A recent survey conducted by J. Veron, the world leader taxonomist of coral reefs, showed the high diversity of the coral reef and identified 220 coral species with five new species in the Eritrean Red Sea. Other important habitats characterize the Eritrean coast, including sea grasses, seaweeds and mangroves. In the Eritrean Sea there are 10 of the 60 species of sea grasses (flowering plants which grow underwater on soft substrates) existing worldwide. A total of 286 seaweed *taxa* (non flowering water dwelling plants) were recorded along the Eritrea's coast, including 50 species of Chlorophyta, 108 species of Phaeophyta and 128 species of Rhodophyta (Ateweberhan, 2004). Moreover, there are three species of mangroves (trees or bushes that grow on soft sediments of the intertidal zone): *Avicennia marina, Rhizophora mucronata* and *Ceriops tagal.* The great diversity of habitats and structural species of the Eritrean Red Sea is mirrored by a very high diversity in fish fauna, which includes more than 1.000 species (Ormond and Edwards, 1987).

HISTORY OF FISHING ACTIVITIES

Fishing sectors

Historically, fishing activities were carried out at a subsistence level using canoes (very small boats, non-motorized, double-ended small crafts) and small plank boats under sail and oar, thus it was an artisanal activity. Since the early 1960s, motorized vessels progressively spread, along with the development of a proper industrial fishery sector.

Artisanal fishery

Nowadays, fishing operations in the Eritrean artisanal fishery are mainly carried out by means of two classes of fishing vessels: *houris* and *sambuqs* (Reynolds *et al.,* 1993). *Houris* are mid-sized units, generally with open decks, fitted with outboard petrol engines (average power 40 hp). They are built with low quality timber of local acacia by nomadic boat builders on orders of fishermen. These boats are long and narrow, typically with a 9-11 m overall length and a 1.5-2 m beam. *Sambuqs* are the largest fishing units (12 to 17 m long), generally decked and equipped with inboard diesel engines (average power 30 hp). These boats are built by itinerant craftsmen at beach locations with imported hard wood and local timber framing, and their shape has evolved over the centuries according to the steep short seas of the southern Red Sea and to allow landing the catches on open beaches. *Sambuqs* are widely used also for trading, transport and carrying goods.

The gears used in the artisanal fishery are mostly gillnets (for sharks and pelagic fish) and handlines (for demersal fish). All activities are manual and make no use of hauling devices. Fishing gears are usually used by their owners, and fishermen work in groups based on their village of origin. These fisheries primarily target reef fish and mid-sized and large

pelagic fish. As a result, catches are predominantly composed of long-lived high trophic level piscivorous species (Ghebremichael and Haile, 2006).
Prior to 1962, there were only very few motorized *houris* and *sambuqs* in use. The first attempts towards the introduction of the engine on fishing boats were made in 1963. In 1970 it was estimated that the artisanal fishing fleet consisted on 500 *houris*, of which 70 equipped with outboard engines, and roughly 300 *sambuqs*, of which 80 had inboard engines (Aubray, 1975). In 1981, however, the fishing fleet consisted only of 130 crafts, of which less than a half were operational. In 1984 the situation seemed to be improved in the Assab area (Dankil region), where almost 56 operational and well-maintained crafts were counted (Guidicelli, 1984). In this year the artisanal fishery was still a financially efficient activity, even though domestic (i.e., Ethiopian) markets were not developed. At present, about 306 *houris* and 152 *sambuqs* are operating in the Eritrean artisanal fisheries (Tsehaye, 2007).

Industrial fisheries

The industrial fishing fleet in the '60s involved up to 4 in-shore trawlers (50–120 hp), 9 off-shore trawlers (150–400 hp) and about 3 handliners (Ben Yami, 1975; Aubray, 1975). After Eritrean independence, an industrial fishery that has been under reconstruction since 1994, with a number of licensed trawlers. The industrial fishing fleet is now characterized by vessels (usually bottom trawlers) capable of fishing in deep waters on the continental shelf (down to 200 m depth). Trawling has been active in Eritrea for a long time and it was also practiced by foreign vessels from Egypt and Saudi Arabia fishing companies, according to annual contract agreements. Currently there are semi-industrial and industrial fishing vessels owned by the Eritrean government, armed with 18 m fiberglass trawlers and long liners as well as 30 meters trawlers respectively.

Trends in Eritrean fishery landings and activities

Landing statistics for the Eritrean fishery are available since the mid 1950's with some gaps up to the late '70s early '80s, due to the many political changes occurred in the country. After Eritrea reached its independence, FAO data statistics for the country are available.

Pre-Independence period (1950s-1992)

In the mid '50s the small pelagic fishery targeting sardine and anchovy was particularly developed, with a production of 25000 t in 1954, and represented the largest proportion (more than 80%) of the catches in Eritrean waters (Figure 2). Small pelagics were processed into fishmeal or sun-dried in Massawa to be exported to European and Far East markets (Aubray, 1975). Production, standing at 21000 t in 1966, dropped to 14000 t in 1967. This was due not to a decline of the productivity of the fishing grounds, but because of the closure of the Suez Canal and, consequently, because of the interdiction of the major fishmeal export route. Fish exports in 1966/67 consisted of only about 5700 t of processed products. By 1972, growing internal warfare and subsequent political instability provoked a further decrease of fishing activities and landings dropped to 4000

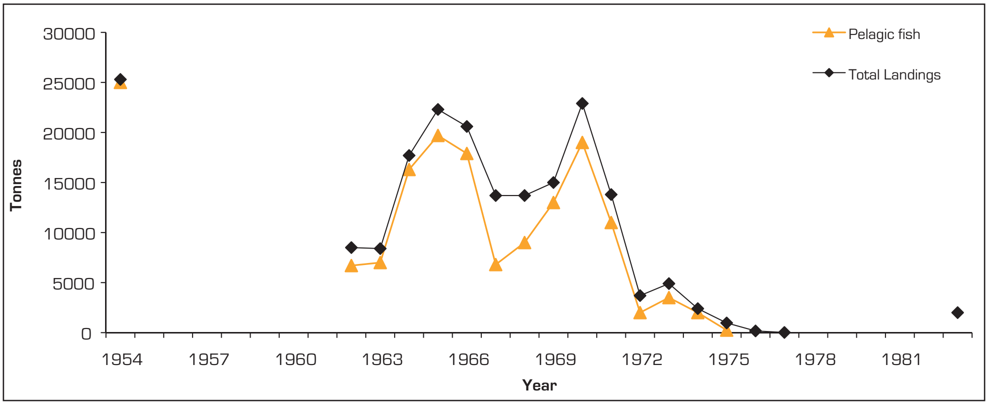


Figure 2. Pelagic fish and total Eritrean fishery yearly landings (tons) (1954-1983). Source: The Fisheries of Eritrea. Data from the '60's come from Grofit (1971).

t. This decreasing tendency continued during the following years. Prior to the war, there was also a fishery targeting demersal species, sharks and crustaceans. Below are reported the Ethiopian government's statistics in Eritrea for these fisheries (Figure 3). The most interesting feature is the increase in shark production at the regional markets corresponding to the temporary closure of small pelagics trade in 1967.

Throughout the war years fishermen traded with Yemen, which was the only market available to sell their products, as well as the only source of foodstuffs and inputs for fishing, which were not available in Eritrea. Fish production of Eritrean fishermen turned predominantly to sun dried and salted sharks and shark fins. Meanwhile, Yemeni fishermen expanded their fishing grounds of demersal fish along the Eritrean coast. The possibility to land and sell fish in Yemen for Eritrean fishermen depended on the goodwill of Yemeni

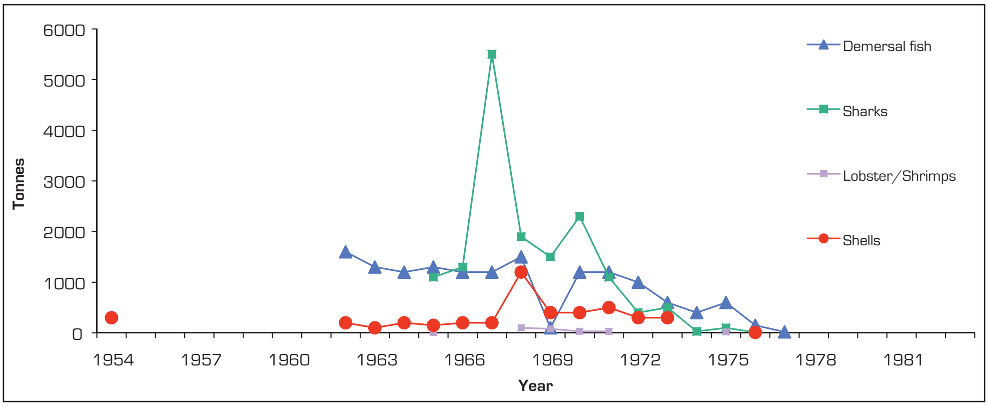


Figure 3. Demersal fish, sharks, lobsters/shrimps and shells yearly landings (Tones) in the Eritrean fishery (1954-1977). Source: The Fisheries of Eritrea; Data from the '60's come from Grofit (1971).

fishermen. Trawl fishing (targeting demersal or bottom fish) in the past was carried out over 5700 km^2 of the Eritrean Red Sea bed. Only approximately 30 tons of shrimps were landed annually in the 1960s. Shrimps were fished in the Zula Bay, Hergigo Bay, and on the Gurgusum grounds.

Post-Independence (1993-2009)

Since the independence of Eritrea in 1993, fisheries started to be revitalized through the building of new or the renovation of old infrastructures along the Eritrean Red Sea coast. In the attempt to maximize fisheries production, new efficient exploitation strategies were introduced, and emphasis was given to the need of expanding both artisanal and industrial fisheries. As a result, catches started to grow, largely dominated by the industrial catches, in particular in 1999. Fishing declined drastically in late 1995 and 1996 in the southern Red Sea due to the territorial dispute with Yemen over the Hanish Islands that determined the closure of the Yemen market. However, the status of exploitation of fishery resources can only be estimated. A fishery catch/effort statistics program began in 1996 in Massawa and Assab.

At present, crustaceans are a resource of increasing interest in Eritrea fisheries; for instance, shrimps showed an increase in landings from only 9 t in 1998 up to 400 t in 2004 (Research and Statistics Division data base, 2005). Other emerging fishing activities in Eritrea are those related to sea cucumbers, “snail nails”, sea snails *Trochus* spp., as well as ornamental fishes and corals for aquarium trade. In particular, sea cucumber fisheries (traded gutted and dried) begun in 2000. Since then, the catches has steadily increased, reaching a production of 278 t in 2006. In 2007, the fishery was closed by an administrative decision to stop illegal fishing and export. *Trochus* spp. shells, used for the manufacture of “pearl-buttons”, were landed at a rate of around 220–250 tons annually in the late sixties, mostly at Massawa. “Snail nails” (opercula of certain conches) have also been heavily exploited in the past around the Massawa area and in the Dahlak Archipelago. Ornamental fishes and corals have been exploited near the islands off Massawa (Madote, Disei, Duhr-Gaham, etc.) and in the Hergigo Bay. At present, the Red Sea Ornamental fish Company (a joint venture with National Fisheries Corporation and other company) is involved in such activities in Eritrea.

Conclusions

The development of fishery exploitation in Eritrea has been largely influenced by the political changes in the country, and this activity is still considered to be under development. Indeed, according to the SeaWiFS1 global primary productivity estimates, the Red Sea is generally considered moderately productive (150–300 gC m^{-2} y^{-1}) (Getahun, 1998) and its resources are considered underexploited. Though a systematic stock assessment of commercially important species is not carried out routinely by the Ministry of Marine Resources, estimates of an aggregate Maximum Sustainable Yield (MSY) for such species range between 70000 and 80000 t (Research and Statistics, Ministry of Marine Resources, Massawa, Eritrea), while previous short-term investigations of specific stocks

carried out between the mid-1950s and the early 1980s, estimated MSY to range between 36000 to 79500 t in the area.
Due to the inherent value of marine biodiversity in the area, a strong management commitment and a strong policy are needed to ensure a well balanced development of the fishery sector of Eritrea. This duty is now accomplished by the effort of the Ministry of Marine Resources who is involved, among other, in the conservation and sustainable use of marine resources, to be achieved through several policies that include closed fishing seasons, marine spatial planning and the enforcement of monitoring and research activities through regulatory proclamations and legal notices (i.e., Eritrean Gazette).

Acknowledgments

I would like to thank the National Fisheries Corporation (NFC), CEO and managers of Eritrea for allowing me to present my paper. I am also grateful to the HMAP organizers and founders, and especially to Dr. Saša Raicevich and Prof. Ruthy Gertwagen. I am also grateful to my family and friends.

Bibliography

Ateweberhan M. (2004). Seasonal dynamics of coral reef algae in the southern Red Sea: Functional group and population ecology. Ph.D. thesis, University of Groningen, the Netherlands. 187 pp.

Aubray R. (1975). The fisheries of Ethiopia: An economic study. Rome, FAO. 23 pp.

Ben-Yami M. (1975). Southern Red Sea fisheries. In World Fishing. pp. 94–99.

Getahun A. (1998). The Red Sea as an extension of the Indian Ocean. In Large Marine Ecosystems of the Indian Ocean: Assessment, Sustainability, and Management, Sherman K., Okemwa E., and Ntiba M. (Eds.). Blackwell Science (Oxford). pp. 277-283.

Ghebremichael A., and Haile S. (2006). Commercial fishes of the Eritrean Red Sea. Apex Publishing Ltd. (Essex). 266 pp.

Grofit E. (1971). The Red Sea fisheries of Ethiopia. Centre for Agricultural Cooperation with Developing Countries, Ministry of Agriculture, State of Israel. 82 pp.

Guidicelli M. (1984). The Ethiopian fisheries: situation, development needs and opportunities. Report prepared for the Fishery Planning and Development Project. Field Document 1. Rome, FAO (FI/DP/ETH/82/016). 157 pp.

Ormond R., and Edwards A. (1987). Red Sea fishes. In Red Sea, Edwards A., and Head S. (Eds.). Pergamon Press (Oxford). pp 252-287.

Reynolds J.E., Appleton J., Bellemans M.S., Bonzon A., and Christy L.C. (1993). The fisheries of Eritrea, part. 1: Sector review. Part. 2: Proposed national fisheries strategy and development program. Terminal Report, FI:FAO/TCP/ERT/2251. FAO, Rome.

Tsehaye I. (2007). Monitoring fisheries in data-limited situations: A case study of the artisanal reef fisheries of Eritrea. PhD Thesis, Wageningen University, the Netherlands, 183 pp. (It can be accessed at http://library.wur.nl/wda/dissertations/dis4309.pdf).

LONG-TERM ECOLOGICAL CHANGES IN THE ADRIATIC SEA

Maja Krželj
Department of Marine Sciences - Polytechnic University of Marche (Italy)
Centre for Marine Studies - University of Split (Croatia)
e-mail: maja.krzelj@unist.hr

Key-words: *time series, Adriatic Sea, long-term changes*

Abstract

In the last decades, there is an increasing number of studies dealing with long term changes in marine environment and impacts of climate change and anthropogenic activities on marine ecosystems in different world regions. Due to its geomorphologic characteristics, emphasized shallowness and sensitivity to changes, the Adriatic Sea, and particularly its northern sub-basin, shows quicker and earlier responses in comparison with other seas, therefore it is a perfect model of research area for studying the environmental variations and responses of marine ecosystems to different impacts.

Ph.D. research in long-term ecological changes in the Adriatic basin, based on analysis of historical trends of environmental and biological factors, was carried on with aim to contribute to a better understanding of the actual status of Adriatic Sea ecosystem in function of changes that have happened in the past. In order to understand ongoing changes and to determinate vulnerabilities of Adriatic Sea, more than 1878000 data from different datasets have been analyzed, considering in the same time the complexity of available data and interconnections between different parameters. For this reason, analysis included in this Ph.D. research work are essentially based on climatological analysis of air temperature, precipitation, Po River inflow, sea temperature, salinity, nutrient concentration, pH and chlorophyll for the period of the last 40 years, together with decadal changes in biological components like small pelagics and demersal resources.

Although the area included in this research has been object of different studies for centuries, it was very difficult to find available datasets, because most of collected data were not published, were not available or were not quantitative.

Introduction

Long-term researches, based on historical dataset analyses, are carried on in order to understand and describe different processes of alteration in marine ecosystem, together with impact of climate fluctuations on marine ecosystems. These researches study relationships between various parameters in time and space, analyzing historical data, with aim to describe patterns of changes and reconstruction of what has happened in the past, in order to explain what is presently happening and to estimate what could happen in the future. For this reason, the availability of long time series is of crucial importance, but it is also important to evidence that long time datasets are usually very limited in space and time. The most complete long time data series are global air temperature records, available since 1860, although some information about earlier climate characteristics can be derived from the combination of historical books, documents, instrumental records and environmental indicators which permit the estimation of past climate conditions, mostly due to palaeoecologic studies. However, long time series data in marine environment are very limited and very short, and although some parameters, like temperature and salinity, are reported for more than 100 years ago, data of biological component usually do not cover more than 50 years (Fonda Umani and Conversi, 2008). Moreover, long-term studies result very important in coastal areas, which are influenced by anthropogenic actions that, in synergy with environmental changes, cause alterations in structure of biocenosis, biodiversity and functioning of ecosystem.

The Adriatic Sea is an epicontinental basin, located in the northern part of the Mediterranean Sea, subdivided in three sub basins: a very shallow northern one (with average depth of 35 m), a central one (with an average depth of 140 m) and a deeper southern one (with maximum depth of about 1270 m in South Adriatic Pit). This sea is highly sensible from the environmental point of view, due to its characteristic morphology of shallow sea with limited exchange of seawater masses and low dilution capacity of pollutants possibly released into the sea. The Adriatic basin represents an important environmental, social and economical resource for all the countries situated in that region, therefore it is very important to preserve and protect it from irreversible losses which may be caused by anthropological pressures like pollution, harvesting of marine organisms and alterations of coastal zones, characteristic for both coasts of the basin. In particular, the northern Adriatic basin is recognized as a region of high production at different trophic levels, with an important region of high biomass and production in the area near the delta of the Po River. Moreover, the Adriatic Sea is one of the most studied marine areas in the world, where generations of scientists have been collecting, analyzing and publishing data, creating a large amount of literature with scientific information which advances our understanding of the sea and allows us to compare the recorded data with the present status, helping us to understand the occurrence of events and alterations in ecosystems. These data are important for understanding changes in biogeochemical characteristic, biodiversity and distribution of marine organisms caused by both climate fluctuations and anthropogenic factors that in synergy influence processes of alteration in composition and functioning of marine ecosystem.

On the other hand, the Adriatic Sea was always, and still is, a strategically important area for maritime traffic, development of commerce and interchange of culture; and its beauty and particularities were always inspiration for writers, poets and artists that have left in their artworks observations and descriptions about many marine organisms, meteorological and oceanographic characteristics of this basin. These artworks can give important information from periods before scientific researches, which can be used in studies of long-term changes together with scientific and non scientific documents. The Adriatic basin was object of numerous studies for more than 300 years, while in the last two decades a big attention was given to changes in functioning of ecosystem services and

alteration of biogeochemical characteristics including phenomena like mucilage, anoxic events, invasive species, changes in composition, atmospheric variability together with changes in physical characteristics and biological component. However, high research importance is given to fishing as it is the most important anthropogenic activity constantly exercised in the Adriatic Sea, which causes important impact on marine ecosystem, not only due to fishing effort but also because the use of trawl nets causes high mortality of non-target benthic organisms and resuspension of sediments, with reintroduction of nutrients and pollutants from sediment in the water column. The importance of fishing influence on marine ecosystem in Adriatic basin is confirmed by Pranovi *et al*. (2005) who have estimated that each square meter of bottom in Adriatic basin is ploughed from two to six times every year because of very intense trawling.
Most of above mentioned studies have been reported for the northern Adriatic basin, therefore its phenomenology is relatively well known, compared to that of the middle and, especially, the southern basin (Artegiani *et al*., 1993), although in the middle Adriatic a number of abiotic and biotic parameters have been studied, especially over the last 50 years (Baranović *et al*., 1993). Moreover, some of these publications tend to deal with investigation of selected living species over a large region, or over the whole Adriatic basin, advancing our understanding and allowing us to look back at the recorded data and compare them with the present status. Such data are invaluable for the analysis of changes that happen over time and occurrence of some events, caused by both natural or anthropogenic factors. One of the longest and more important time series available for the Adriatic basin report mucilage events and dates back to 1729, with events reconstructed on the basis of scientific papers and records in old newspapers (Fonda Umani *et al*., 1989).
In this Ph.D. research, climatological analyses of air temperature, precipitation, Po River runoff, sea temperature, salinity, nutrients concentration, pH and chlorophyll for the period of the last 40 years, together with decadal trends in biological components (small pelagics and demersal resources) were carried on in order to describe the status of Adriatic Sea ecosystem and changes that have happened during the last decades.

Long time series used in Ph.D. research in long-term ecological changes in the Adriatic Sea

Climatological analyses in this research include anomalies of surface air temperature, Po River runoff, marine physical parameters and nutrients of the northern Adriatic Sea, with maps produced for decadal seasonal (also bimonthly for temperature and salinity) anomalies in the northern Adriatic Sea. All variables were analyzed on seasonal basis (January, February, March for winter; April, May, June for spring; July, August, September for summer; October, November, December for autumn); while marine parameters were subdivided and analysed, apart in the surface layer, also at intermediate level (20 m depth) and in the bottom layer (within 5 m from the sea bottom), for the period 1970-2008, obtaining spatial anomalies for the last 18 years in comparison with the 1970-1989 period. In order to identify possible statistically significant trends and regime shifts of physical, chemical and biological parameters during the last 15-40 (depending on data availability) years, statistical trend analyses (Mann-Kendall test for trend and Sen's slope es-

timates; MAKESENS) and regime shift analyses (Regime Shift Detection Method), were applied on all data included in this study in order to obtain more detailed and more statistically precise results analyzing annual (all parameters) and seasonal (physical and chemical parameters) trends and regime shifts.
Moreover, before applying statistical analyses, all marine parameters have been subdivided in four seasons, three depths (surface, intermediate and bottom layer) and three areas with different characteristics called "Po", "Est" and "Nord". The first one is under direct influence of Po River outflow, the second is representative of eastern area, the third is not directly influenced by the Po River and it is frequently interested by a cyclonic gyre, In this three areas data were available in several years, allowing for statistical analysis of relatively long time series.
As already mentioned, the area of interest in this research has been studied for centuries, but it was very difficult to find available datasets that contain necessary data, mostly because some of these are not published, or if they are published, it was not possible to get them or to use them. Fortunately, some of datasets necessary for this study were available online, while others were gently offered by research institutions and researchers; long time series used for data elaboration in this research are here reported:
Meteorological Observatory of Institute Cavanis from Venice in Italy contains data recorded in a meteorological station situated on latitude 45°25'48''N, longitude 12°19'25''E and altitude 18,08 meter above the mean sea level. This research institute presents a long-term database that includes daily data of air temperature, air pressure, humidity, vapour tension, precipitation, cloudiness, wind direction, wind speed and solar radiation, for the period 1901-2005.
NOAA (National Oceanic and Atmospheric Administration) is agency that date back to 1807 and contains over 9000 worldwide stations, with different and numerous datasets regarding issues of climate changes, weather, oceans, fisheries, etc. In this study were used surface summary daily data provided for northern Adriatic basin, based on data exchanged under the World Meteorological Organization (WMO) World Weather Watch Program, with following daily elements available from each station: mean temperature, mean dew point, mean sea level pressure, mean station pressure, mean visibility, mean wind speed, maximum sustained wind speed, maximum wind gust, maximum temperature, minimum temperature, precipitation amount, etc.. Historical data are generally available for 1929 to the present, with data from 1973 to present being the most complete.
ISAC-CNR (Institute of Atmospheric and Climate Sciences - Italian National Research Council) Historical Climatology Group represents a long period of historical air temperature and precipitation data over the entire Italian peninsula starting from 1800s. In this research were used data recorded in stations situated along the Italian coast in the northern Adriatic basin.
Magistrato del Po and **ARPA Emilia Romagna** datasets of Po River average flow **at Pontelagoscuro** contain monthly historical data for the period 1918-2008 and daily data for the period 1983-2006.
ISMAR-CNR (Institute of Marine Science - National Research Council) dataset includes data of sea temperature, salinity, oxygen, chlorophyll, pH, nitrates, nitrites, ammonia, phosphates, silicates and fluorescence, that were used to described climatological changes in Northern Adriatic basin. In this research this database was corrected and restricted

in the period of the last 40 years and only for the area of the Northern Adriatic basin, so in this version it includes more than 12800 stations with data of temperature and salinity, almost 8000 stations with oxygen and more than 6500 with pH data, while there are more than 3000 stations with nutrients, chlorophyll and fluorescence data.
MEDATLAS 2002 is integrated dataset, produced due to wide international cooperation within the framework of the project MEDAR/MEDATLAS, containing data available for the Mediterranean and the Black seas with the following parameters: temperature, salinity, dissolved oxygen, nitrate, nitrite, phosphate, silicate, ammonium, alkalinity, pH, chlorophyll, hydrogen sulphide, total nitrogen, and total phosphorus. Adriatic data have been checked in order to exclude repetitive stations and non credible data, and once controlled in this way, the new dataset contained more than 11000 stations with temperature and salinity data, more than 8000 stations with oxygen data and more than 3800 stations with pH and nutrients data.
SIDIMAR dataset contains data from all Italian coastal regions for the period 2001-2007, obtained from continuous monitoring in coastal waters of Adriatic, Ionian and Tyrrhenian Sea, offered by Italian Ministry of Environment, Territory and Sea, and contains data of physical parameters, nutrient parameters, plankton (phyto- and zoo-) data, benthos data and data of some pollutants along the entire Italian peninsula, for the entire period 2001-2007. In this study were used data from 18 stations situated in the northern Adriatic basin, with 6218 samplings of temperature, salinity, oxygen, pH, chlorophyll and nutrients.

MEDAR/MEDATLAS 2002 and CNR-ISMAR datasets were analyzed with aim to create maps of periodical, seasonal and bimonthly, spatial patterns and anomalies of temperature and salinity in northern Adriatic Sea. Before the elaboration of data, further control of data quality was made in order to exclude non-credible, bad or repetitive data and stations. After the quality check, data were imported in *Ocean Data View* program and selected in base of research hypothesis: two periods (1970-1989 and 1990-2008), four seasons (winter, spring, summer and autumn), three depth levels (sea surface, 20 meters and bottom) and ten different parameters (temperature, salinity, pH, oxygen, chlorophyll, nitrates, nitrites, ammonia, phosphates and silicates). The 240 climatological maps have been produced from data selected for extraction and their subsequent spatial interpolation by means of an Objective Analysis procedure developed after the works by Gandin (1965), Bretherton *et al*. (1976) and Carter and Robinson (1987), as applied in Russo *et al*. (2002). The interpolation has been made according to the optimal linear estimation theory, based on the Gauss-Markov theorem. Thereafter, the interpolated fields were loaded in the mapping software *Surfer*, in order to produce maps and statistics elaborations of parameters in the northern Adriatic basin. From spatial fields loaded in Surfer, 120 maps of anomalies were obtained by subtracting grid of the first period from the last period. From these anomaly maps, made for four seasons, three depth levels and 10 parameters, it is possible to observe changes in the northern Adriatic of the last two decades in comparison to the previous two decades (taken as reference period). The same procedure was used for bimonthly analysis.

CNR-ISMAR-SPM Ancona dataset of small pelagic stocks in Geographical Sub Area 17, situated in northern and central Adriatic Sea, was used to estimate fluctuations for both

anchovy and sardine stocks. Estimates of stock biomass were obtained by means of VPA with Laurec-Shepherd tuning (software by Darby & Flatman, 1994) using total catch including catches of Italy, Slovenia, Croatia. This dataset includes data of total catch, total stock biomass, spawning stock biomass, and number of recruits for both anchovy and sardine in the period 1976-2007 and it was gently lent by CNR-ISMAR.
The MEDiterranean International Trawl Survey (MEDITS) programme was established in 1993 with the aim to produce basic information on benthic and demersal species in term of population distribution and demographic structure, through systematic bottom trawl surveys. Dataset used in this study includes data of total catch and total stock biomass for the period 1996-2008, situated in Geographical Sub Area 17 (in northern and central Adriatic Sea), which was gently lend by Institute of Oceanography and Fisheries in Split (Croatia) and *Laboratorio di Biologia Marina Fano* (Italy). The gap of data in 1999 is due to the presence of NATO military operations in Adriatic basin and impossibility of survey research in that period.

Conclusions

All projections concerning future changes in marine environment should take into account the analyses of the present situation and the assessment of the trends observed in the past, because the comparison between recent and past conditions allows us to understand whether, and in what measure, changes have occurred in the past and could occur in the future. Understanding of the ecosystem functioning and long-term changes in marine environment is possible due to sustained monitoring and comparison of historical data with the present state; for this reason, the historical data have crucial importance in understanding of the previous state and ongoing changes.
Apart the increased number of stations, an important novelty of the marine physical analysis is the investigation of changes of the subsurface layers, reported in this Ph.D. research work. Results obtained from the analyses show that the northern Adriatic Sea during the last two decades has been influenced by a generalized warming of air temperature in all seasons, together with changes in precipitation pattern and a varying Po river runoff that are linked to many variations of marine properties showed in the results. In fact, analyses indicate that during the last decades the Adriatic Sea (in particular its northern part, where this study mainly focussed because of data availability) has been undergoing to relevant changes at different levels of the ecosystem organization. Moreover, statistical analysis demonstrates that such changes occur in some cases as long-term trends, in others as regime shifts, in some others as both. Climatic factors, i.e. changes in air temperature and precipitation, drove relevant changes in river runoff, thermohaline and biogeochemical properties of the northern Adriatic, which in turn drive marine ecosystems changes; some of them are evident in terms of the abundance of small pelagic and demersal resources, in particular crustaceans, cephalopods and fishes, while anthropogenic synergistic effects are detectable, but they could not be quantified in this thesis work.
The main problem of this research indeed was finding available good quality data that could be used for the above-mentioned analysis. Although the area included in this re-

search for centuries has been object of several studies, it was very difficult to find available datasets, because most of collected data are not published, and even if they were published often it was not possible to get them or to use them. Therefore it is possible to conclude that the main obstacle in this research was the fact that the major quantity of existent data were not available or they were undercovered, while data found in bibliography were not always quantitative. The great difficulties in catching the data encountered in this thesis stress the importance of promoting and carrying out regular monitoring of many marine variables and their diffusion in databases.

Bibliography

Artegiani A., Gačić M., Michelato A., Kovačević V., Russo A., Paschini E., Scarazzato P., and Smirčić A. (1993). The Adriatic Sea hydrology and circulation in spring and autumn (1985–1987). Deep-Sea Research 40: 1143–1180.

Baranović A., Šolić M., Vučetić T., and Krstulović N. (1993). Temporal fluctuations of zooplankton and bacteria in the middle Adriatic Sea. Marine Ecology Progress Series 92: 65-75.

Bretherton F.P., Davis R.E., and Fandry C.B. (1976). A technique for objective analysis and design of oceanographic experiments applied to MODE-73. Deep-Sea Research 23: 559–582.

Carter E.F., and Robinson A.R. (1987). Analysis models for the estimation of Oceanic Fields. Journal of Atmospheric and Oceanic Technology 4: 49-74.

Darby C.D., and Flatman S. (1994). Virtual Population Analysis: version 3.1 (Windows/Dos) user guide. Info. Tech. Ser. MAFF Direct. Fish. Res., Lowestoft, 1, 85 pp.

Fonda Umani S., and Conversi A. (2008). Possible climate impacts on the northern Adriatic pelagic ecosystem; Climate warming and related changes in Mediterranean marine biota. Helgoland, 27-31 May 59 CIESM Workshop Monographs n°35.

Fonda Umani S., Ghirardelli E., and Specchi M. (1989). Gli episodi di ‘mare sporco’ nell'Adriatico dal 1729 ai giorni nostri. Regione Autonoma Friuli-Venezia Giulia, Direzione Regionale Ambiente, Trieste.

Gandin L.S. (1965). Objective Analysis of Meteorological Fields. Israel Program for Scientific Translations. 242 pp.

Pranovi F., Raicevich S., Libralato S., Da Ponte F., and Giovanardi O. (2005). Trawl fishing disturbance and medium-term macroinfaunal recolonization dynamics: a functional approach to the comparison between sandy and muddy habitats in the Adriatic Sea (Northern Mediterranean Sea). In Benthic habitat and the effects of fishing, Barnes P.W., and Thomas J.P. (Eds.). American Fishery Society Symposium, Symphosium. Bethesda (Maryland). pp. 545-569.

Russo A., Rabitti S., and Bastianini M. (2002). Decadal climatic anomalies in the Northern Adriatic Sea inferred from a new oceanographic data set. P.S.Z.N.: Marine Ecology 23, Supplement 1: 340-351.

SPACE AND TIME CHARACTERIZATION OF PHYSICAL AND BIOCHEMICAL PARAMETERS IN THE ADRIATIC SEA USING VARIATIONAL METHODS AND STATISTICAL ANALYSIS

Anna Rabitti
Master Thesis in Physics, University of Trieste, supervisor dott. Alessandro Crise (OGS), a.a. 2007/2008.
e-mail: anna.rabitti@nioz.nl

Key-words: *Adriatic Sea, climatological maps, historical data, temperature, salinity*

A new spatial-temporal climatological characterization of the Adriatic Sea has been performed, using Diva (Data Interpolating Variational Analysis), version 4.2.1, advanced software for geostatistical analysis of oceanographic fields, developed by GHER group from Liege University (Belgium) (Rixen *et al.*, 2000). Applying the Variational Inverse Method (VIM) and a resolution by Finite Element Method, implemented in Diva, a reconstruction of physical (temperature and salinity) and biochemical parameters (concentration of dissolved oxygen, silicates, nitrates and chlorophyll) in the Adriatic basin has been finalized, using in situ measures available in the database of the *Istituto Nazionale di Oceanografia e Geofisica Sperimentale* (Trieste, Italy). The products of this characterization are annual, seasonal and monthly climatological horizontal maps of the basin.
In order to obtain the horizontal maps both historical and recent data have been used, in the time range 1900-2008: regarding the Adriatic Sea the whole dataset contains, for instance, about $2.5*10^6$ measures for temperature, $2*10^6$ measures for salinity, $1*10^6$ measures for dissolved oxygen, $2.5*10^4$ measures for phosphate concentration. In Figure 1 an example of the analyzed datasets is depicted: surface temperature measurements are presented for the four different seasons.
The field reconstruction has been made in collaboration with the GHER group; many of the statistical tools available in the Diva package have been tested with and applied to the real Adriatic dataset, bringing general improvements to the software, and suggesting the implementation of new personalized features for the analysis.
The two main parameters required for the analysis are the correlation length (L) and the signal to noise ratio (S/N), relative to each dataset. The first parameter represents the scale length that has to be used to write the problem in a non-dimensional Form. It is also linked to the spatial scale resolved in the reconstruction. It represents the correlation length typical of each dataset, regarding to the horizontal distribution and total number of the measurements in the domain. The dimension of the resolution mesh (example in Figure 2) depends on this parameter. The second parameter, S/N, is used to evaluate the error maps. Due to a non homogeneous data coverage, an objective estimation of the two parameters directly from statistical properties of the datasets was not possible. Eventually the values have been chosen manually (L = 0.8°, S/N = 0.5), taking into ac-

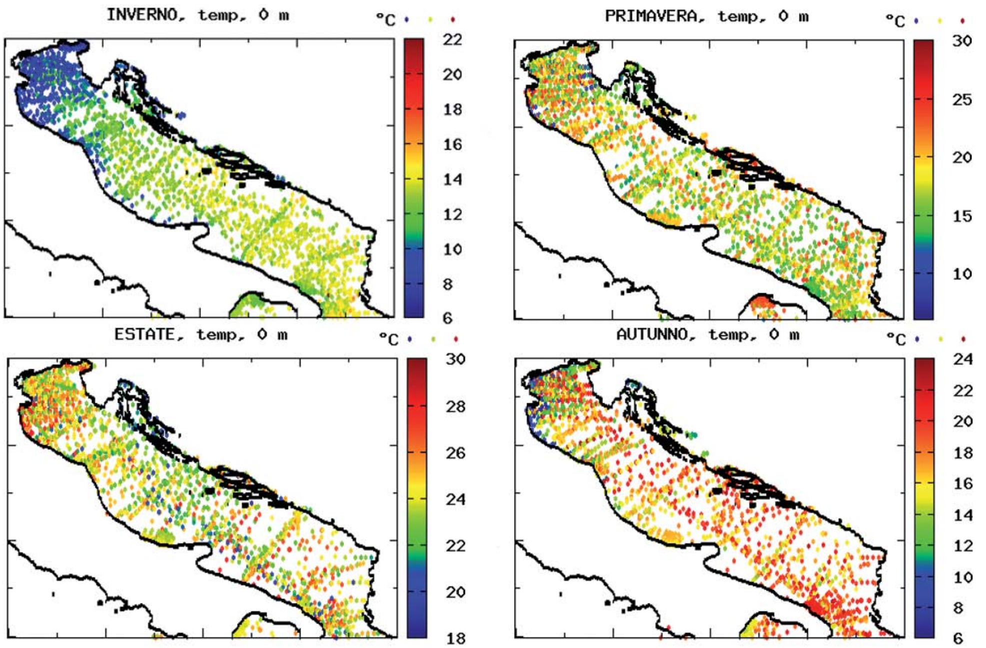


Figure 1. Seasonal Surface temperature. Temperature is in Celsius degree.

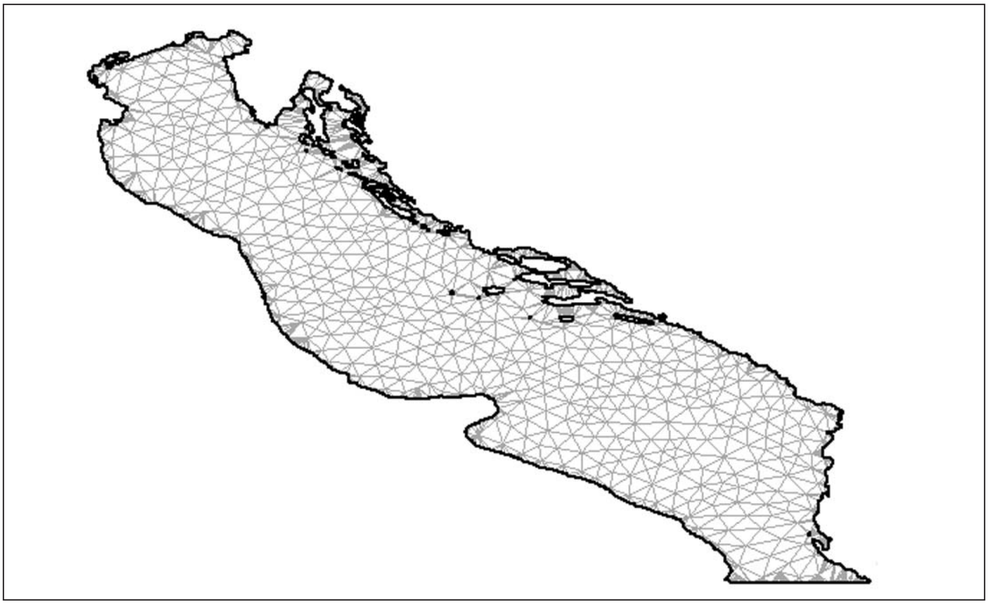


Figure 2. Example of analysis mesh. Mesh used in the winter surface temperature field reconstruction.

count the scale length of the structures that had to be pointed out with the climatological analysis, and other characteristics features of the analyzed dataset.
A cross validation test on the application of the method to the Adriatic dataset was performed (Brankart and Brasseur, 1996), obtaining a low method-linked variability compared to the proper space and time variability of the real fields, and allowing the application of the analysis method on the whole dataset.
No previous study, indeed, had addressed the Adriatic variability in a context of fully systematic application of the same methodology to the whole Adriatic dataset. The climatological maps produced are evaluated on a regular grid of 1/16 of degree for each of the 28 layers of interest, from surface to 1200 m depth, with increasing resolution from the bottom to the surface.
The seasonal and monthly climatological maps for temperature (example in Figure 3), salinity, and dissolved oxygen have been compared (where it has been possible) with literature and have been found in complete agreement with the previous field reconstruction (Artegiani *et al.*, 1997a; Artegiani *et al.*, 1997b; Zavatarelli *et al.*, 1998). The reconstructed vertical profiles have been compared with those ones in literature, resulting from observational profiles, showing an elevated level of confidence. It is worth noting that the maps relative to different depths are independently evaluated and the vertical coherence can be seen as a further success of the analysis methodology. The different water masses, relative to each of the three sub basins (Northern, Middle and Southern) of the Adriatic Sea, have been

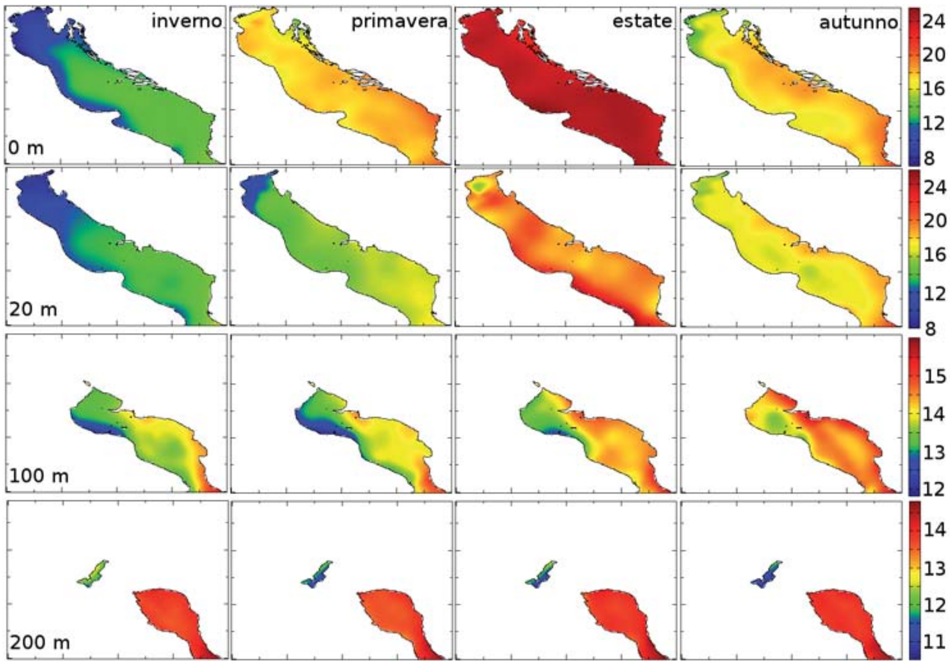


Figure 3. Reconstructed temperature fields. Left to right, the four seasons; top to bottom, four different depths. Temperature is in Celsius degree.

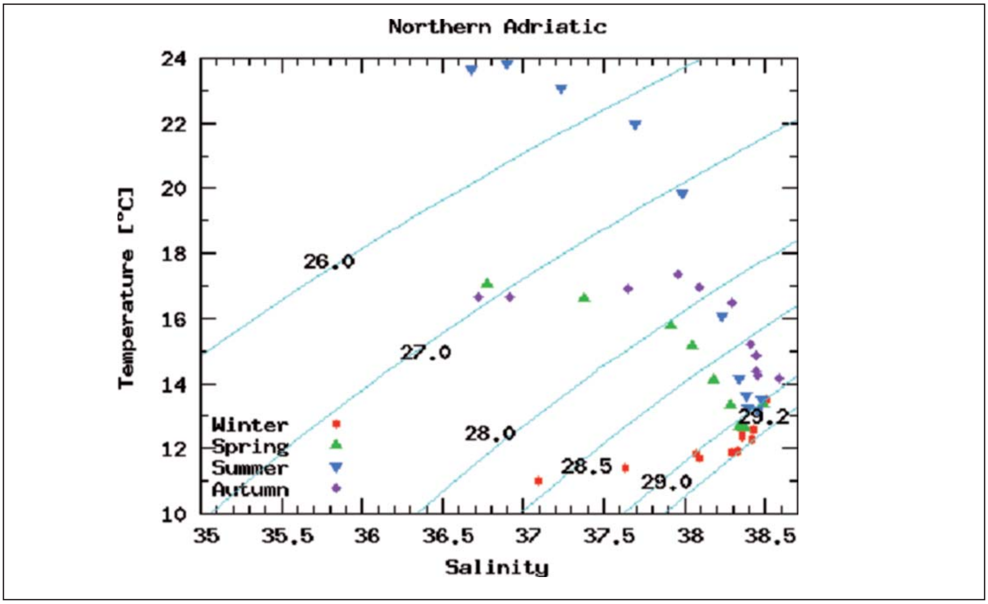


Figure 4. Seasonal T-S diagram for Northern Adriatic Sea, evaluated from the reconstructed fields. Isodensity lines are depicted in light blue (kg/m^3).

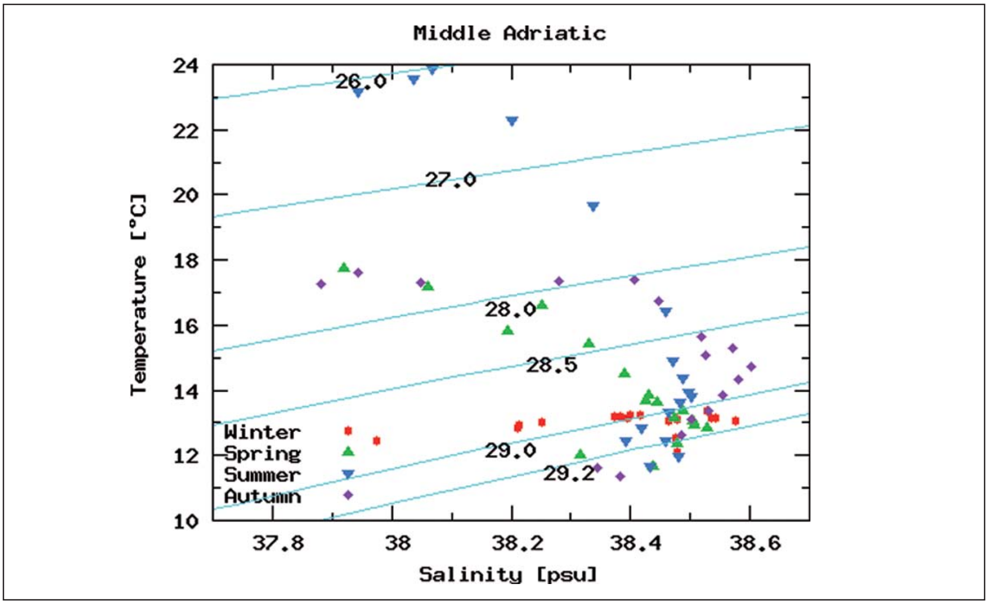


Figure 5. Seasonal T-S diagram for Middle Adriatic Sea, evaluated from the reconstructed fields. Isodensity lines are depicted in blue (kg/m^3).

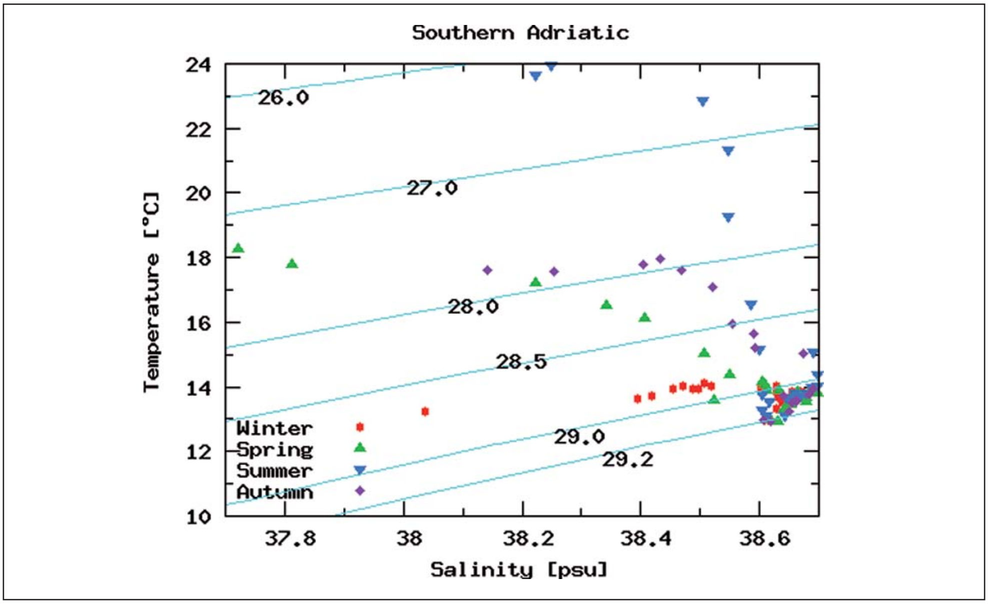


Figure 6. Seasonal T-S diagram for Southern Adriatic Sea, evaluated from the reconstructed fields. Isodensity lines are depicted in blue (kg/m^3).

seasonally evaluated, recognized and compared with literature, obtaining a complete picture of the features of the basins through T-S diagrams, as in Figures 4, 5 and 6.

For three parameters, temperature, salinity, and dissolved oxygen, a further study about the decadal variability on century-scale has been started, in order to derive possible time trends and variability of the fields data from the 1914-1918 campaigns, and from the last three complete decades (1970, 1980, 1990) have been take into account for the analysis. An increase in time has been detected in the surface temperature in the three sub basins, with different behaviors in the deeper layers, and a general decrease in salinity can be observed in the last decade, but further analysis are required in order to give a reliable interpretation of the evolving profiles.

For nutrients and other biochemical parameters, only annual climatological maps have been produced, since the paucity of the measures and a strong non homogeneous data coverage did not allow a more detailed reconstruction. The resulting profiles show some evident structures, mainly related to the Po river, discharging its waters in the northwest part of basin. New data are necessary to depict a complete picture of the patterns for these parameters.

All the maps were produced in compliance with SeaDataNet European Project's guidelines (www.seadatanet.org). The aims of this project are those of creating an international network connecting the numerous European National Oceanographic DataCenter, and providing the users with updated climatologies, to initialize numerical prediction models and validate new datasets from recent cruises or campaigns.

Bibliography

Artegiani A., Bregant D., Paschini E., Pinardi N., Raicich F., and Russo A. (1997a). The Adriatic Sea general circulation. Part I: air-sea interactions and water mass structure. Journal of Physical Oceanography 27: 1492-1514.

Artegiani A., Bregant D., Paschini E., Pinardi N., Raicich F., and Russo A. (1997b). The Adriatic Sea general circulation. Part II: Baroclinic circulation structure. Journal of Physical Oceanography 27: 1515-1532.

Brankart J., and Brasseur P. (1996). Optimal analysis of in situ data in the Western Mediterranean using statistic and cross-validation. Journal of Atmospheric and Ocean Technology 13: 477-491.

Rixen M., Beckers J., Brankart J., and Brasseur P. (2000). A numerically efficient data analysis method with error map generation. Ocean Modelling 2: 45-60.

Zavatarelli M., Raicich F., Bregant D., Russo A., and Artegiani A. (1998). Climatological biogeochimical characteristics of the Adriatic Sea. Journal of Marine Systems 18: 227-263.

ISBN 978-88-448-0470-1