Ecopath 30 Years
Conference Proceedings:
Extended Abstracts
ECOPATH 30 YEARS CONFERENCE PROCEEDINGS: EXTENDED ABSTRACTS

edited by

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FOREWORD

The baby has turned 30, so no longer a child. It’s time to grow up and take responsibility – that was the challenge I put forward to the participants at the closing of the Ecopath 25th Anniversary Conference five years ago at UBC. So, how is it doing? A check using Google Scholar will show that Ecopath is still popular, being referenced by 321 publications in 2010, and 399, 359, and 362 the following years, and 285 so far in 2014 – that’s one citation per day. But being popular doesn’t really indicate that one has grown up, though on that front there indeed has been significant development since the last Anniversary.

The dynamic modeling in EwE has seen major additions, the spatial modeling is breaking new grounds, there have been major developments on plug-ins, and we have seen new model types being developed and published. What I find especially promising is the development on model coupling related to climate change research and the associated new capabilities for spatial modeling. Still, having learned great skills as part of one’s education, doesn’t necessarily translate into taking responsibility later in life – though it certainly is good ballast.

Moving from the academic world to the more applied is a challenge, also because fisheries management as a rule is rather reactive being focused on tactical issues. Where ecosystem-based methods have the strongest contribution to make for management is in relation to strategic management, i.e. mid-term questions about ecosystem changes and the associated tradeoffs for management. Ecosystem-based methods indeed have a strong role to play for management, and while we do see major progress on this front, notably in Europe and Australia, we still have a long way to go – so my challenge from 2009 stands.

But the Ecopath 30th Anniversary Conference is on track to help move us toward ecosystem based management (EBM), and the success that is clearly indicated by the interest in the conference – as the extended abstracts in this volume is a strong indicator of – will serve as a milestone. The contributions range wide, starting off indeed with scientific advice for management, and on to marine conservation, ecosystem evolution, cumulative dynamics, and end-to-end. Overall, this shows the versatility of the approach and even more importantly, how the diversity of scientists that cooperate on moving us toward EBM jointly can contribute to a scientific development that is bigger than what any of us can accomplish individually.

Synergistic cooperation is indeed the key issue for Ecopath and where we are heading. This is the foundation for the Ecopath Research and Development Consortium, which was established in 2011, and which now has close to 20 institutional members from throughout the world. We invite you all to join the effort.

Villy Christensen

Co-Director

Fisheries Centre, UBC
Since the very successful 25 years of Ecopath conference, 5 years ago the Ecopath with Ecosim and Ecospace approach has gone from strength to strength. The Ecopath Research and Development Consortium (www.ecopath.org/consortium) was formed in 2011, and we have increased our presence in Europe with a new office in Barcelona (http://ecopathinternational.org/).

A Google Scholar Search of Ecopath from 2009-2014 provided 2,120 results, with at least 100 papers published since 2009. Thus the 200 publications mentioned in the Ecopath 25 years conference has been substantially enhanced in the past 5 years.

The *Ecopath 30 Years Conference and Workshops* (4th-14th November 2014, Barcelona, Spain) aims to highlight how EwE has moved beyond the boundaries by modelling ecosystem dynamics. We will showcase 30 years of progress using the Ecopath approach in fields such as fisheries management, marine conservation, ecosystem dynamics, climate impacts, and ecosystem-based-management, as well as to introduce exciting new functionalities of the approach.

We wish all participants a fruitful stay in Barcelona and two very exciting weeks at the *Ecopath 30 Years Conference and Workshop Events*!

THE ORGANIZING AND SCIENTIFIC COMMITTEES -
ECOPATH 30 YEARS CONFERENCE AND WORKSHOPS
THE ORGANIZING AND SCIENTIFIC COMMITTEES

ORGANIZING AND SCIENTIFIC COMMITTEE OF THE ECOPATH 30 YEARS CONFERENCE AND WORSHOP EVENTS:

Beth Fulton, CSIRO Marine and Atmospheric Research, Hobart, Australia
Chiara Piroddi, Joint Research Centre, European Commission, Ispra, Italy
Didier Gascuel, Fisheries and Aquaculture Sciences Centre Agrocampus Ouest, Rennes, France
Ekin Akoglu, Instituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy
Francisco Sánchez-Arreguin, Centro Interdisciplinario de Ciencias Marinas, Baja California Sur, Mexico
Isabel Palomera, Institute of Marine Science, Spanish Research Council, Barcelona, Spain
Jeroen Steenbeek, Ecopath International Initiative Research Association, Barcelona, Spain
Johanna J. Heymans, Scottish Association for Marine Science, Oban, Scotland
Lynne Shannon, Marine Research Institute, University of Cape Town, South Africa
Marta Coll, Institute of Research for the Development of Exploited marine Ecosystems, Sète, France
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Steve Mackinson, Centre for Environment, Fisheries and Aquaculture Science, Lowestoft, UK
Villy Christensen, University of British Columbia, Vancouver, Canada
ACKNOWLEDGEMENTS

The *Ecopath 30 Years Conference and Workshop Events* were made possible through the support of the following institutions, sponsors and individuals:

Several members of the Ecopath International Research and Development Consortium (www.ecopath.org/consortium) contributed actively by providing time for several staff to participate to the organisation of the events.

The main institute behind the organization of the event was the Ecopath International Initiative (http://ecopathinternational.org/), the European office of the Ecopath and Research Consortium.

The Institute of Marine Science (www.icm.csic), from the Spanish Research Council (Barcelona, Spain), graciously provided the venue for the events.

Abstracts submitted to this conference were reviewed by an international scientific committee comprising of: Chiara Piroddi (JRC, Europe), Didier Gascuel (Agrocampus, France), Ekin Akoglu (OGS, Italy), Elisabeth A. Fulton (CSIRO, Australia), Francisco Arreguín-Sánchez (CICIMAR, Mexico), Johanna J. Heymans (SAMS, UK), Lynne Shannon (UCT, South Africa), Marta Coll (IRD, France), Sebastian Villasante (USC, Spain), Simone Libralato (OGS, Italy), Steve Mackinson (CEFAS, UK), and Villy Christensen (UBC, Canada). We thank the scientific committee for the chairing of the sessions of the conference.

We thank Villy Christensen (Opening Session and Session VI), Steve Mackinson (Session I), Tony Pitcher (Session II), Ken H. Andersen (Session III), Joanna J. Heymans, (Session IV), Marta Coll (Session IV & V) and Kerim Aydin (Session V) for being the keynotes of the conference sessions.

The conference promotion material (banners, stickers, logos, T-shirts), name tags, certificates, and website were designed by Jeroen Steenbeek.

The materials provided to the participants (bags, mugs, notebook, pen) were made possible with the professional help of William Dunwell from “Anything But Cattle” (UK). The Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (www.ogs.trieste.it/) and the Scottish Association for Marine Science (http://www.sams.ac.uk/) provided the USB keys for the conference and workshops. The City Hall of Barcelona provided free touristy information to participants.

The Fisheries Centre (www.fisheries.ubc.ca), University of British Columbia, made possible the publication of these proceedings.

Tours to the CosmoCaixa Barcelona Science Museum were made available free of charge for participants to the events thanks to “La Caixa” Banking Foundation. Additional free tours were made available for participants thanks to the Maritime Museum of Barcelona (ewe30.ecopathinternational.org/trips-and-excursions/).

The organizers wish to thank all students and staff of the Institute of Marine Science from the Spanish Scientific Council (Barcelona, Spain) who volunteered to help out with the various and many tasks involved in making this conference run as smoothly as possible: Isabel Palomera, Anabel Colmenero, Claudio Barria, John Ramierz, Marta Albo, Samuele Tecchio, Sònia Sanchez.

Aurora Requena and Eli Bonfill from “Plàncton, Divulgació i Serveis Marins” are acknowledged for their professional help in the organization of the event.

Acknowledgements
ON BEING GREEN

The Ecopath 30 Years Conference and Workshops Events Organizing Committee made an attempt to be ‘ecological’ and to employ ‘sustainable’ resources by:

(i) providing a website where documents relevant to the Conference and Workshops can be viewed and/or downloaded, thus supporting a ‘paperless’ option;

(ii) choosing a green option for the materials provided to participants (bags, mugs, notebook, pen);

(iii) providing non-disposable coffee mugs;

(iv) using non-disposable dishes, glassware and cutlery during coffee breaks, lunches and welcoming reception; and

(v) providing water to all presenters in recyclable cups and non-disposable jars.

The food catering is brought to the conference and workshops through the Movie Blues local caterer (http://ewe30.ecopathinternational.org/catering/), who will serve “Slow Food” using local ecological ingredients.

Participants are encouraged to use the cloth bags and coffee mugs provided to them during the conference and the workshops, or when buying at the nearby cafés and shops.
VENUE AND INSTRUCTIONS

The Ecopath 30 Years Conference and Workshop Events will be held at Institute of Marine Science (ICM-CSIC) Passeig Marítim de la Barceloneta, 37-49, E-08003, Barcelona (Spain); Tel. (+34) 93 230 95 00; Fax. (+34) 93 230 95 55; Website: www.icm.csic.es.

Presentations and keynotes of the conference will be hosted at the conference room (floor -1); all courses (the introductory course and the advance courses) will be hosted at room P31 (floor +1), except Ecotroph workshop that will be hosted at room P41 (floor +1). Just follow the signs to find your room.

Oral presentations will be allocated 15 minutes (including questions), except keynote presentations that will be 30 minutes (including questions). Please submit your oral presentations to the registration desk when you arrive at the conference. Presentations must be delivered as Adobe PDF (.pdf) or PowerPoint (.ppt/.pptx) files. We do not support KeyNote files.

Posters should be in vertical format A0 (width 841mm x height 1189mm, portrait orientation). Posters should be put on the first day of the conference during the morning and will be on display for the entire conference. Please remove your posters at the third day of the conference, after the poster session (12.30-14.00).

Posters should be briefly presented at dedicated ‘poster presentations’ scheduled the end of each Conference session. Each poster presentation is brief, no longer than 3 minutes per poster, with a maximum of 3 slides.

Please submit your poster presentations to the registration desk when you arrive at the conference. Presentations must be delivered as Adobe PDF (.pdf) or PowerPoint (.ppt/.pptx) files. We do not support KeyNote files.

Poster sessions will be concurrent with the welcome reception the first day of the conference (10th of November 2014) and lunch breaks of the second and third day (11-12th November 2014), which will be held at the patio (floor 0) and in the cafeteria of the Institute of Marine Science (floor +1), respectively.

Wifi Internet access can be obtained through Portal-CSIC. Please inquire at the registration desk for details.
PROGRAM

DAY 1: MONDAY 10TH NOVEMBER

Master of Ceremony: Sheila Heymans (SAMS, UK)

08:00 – 09:00  Registration
09:00  Opening by Master of Ceremony
09:00 – 10:00  Welcome
09:00 – 09.30  Isabel Palomera, Senior Researcher at ICM-CSIC and head of the local organization committee
Albert Palanques, Director of the Institute of Marine Science
09:30 – 10.00  Opening keynote by Dr. Villy Christensen:
Modelling marine ecosystems: Lessons learned and the road ahead
10:00 – 10.30  Coffee break
10.30 – 13:30  Session 1 – Scientific advice for management: from research to advisory tools
Chairs: Steve Mackinson (CEFAS, UK), Villy Christensen (UBC, Canada)
10:30  Keynote by Dr. Steve Mackinson:
A European perspective on modelling to support an ecosystem approach to management
11:00 – 13:15  Oral presentations
11:00  Adebola & De Mutsert – Reducing Anthropogenic Impacts on Nigerian Coastal Fisheries Resources
11:15  Bacalso & Wolff – Dynamic simulation model of illegal fishing gear removals in the Danajon Bank, Central Philippines
11:30  Fondo et al – The impacts of changes in prawn trawling effort on trophic structure after establishment of a Marine Park
11:45  Giacaman-Smith et al – Analysing recovery in the main demersal stocks from southern Chile in a multispecies context
12:00  Griffiths et al – Just a FAD? Potential ecological impacts of tuna purse seine fishing on Fish Attracting Devices in the western Pacific Ocean?
12:15  Meissa et al – Diagnosis of the ecosystem impact of fishing and trophic interactions between fleets: a Mauritanian application
12:30  Morato et al – Towards ecosystem based management of the Azores marine resources
12:45  Staebler et al – Potatoes of opportunity for fishing in the southern North Sea
13:00 – 13:30  Poster presentations
Angelini et al – Comparing the maximum sustainable yield of commercial stocks with the ecosystem sustainability of fishing
Bundy & Guénette – Loosening the corset: how real are wasp-waist ecosystems?
Halouani et al – How Fishing impacts Mediterranean marine ecosystems? An EcoTroph modeling approach
Kluger et al – Carrying capacity simulations as a tool for ecosystem-based management of a scallop aquaculture system
Lercari et al – A food web analysis of the Río de la Plata estuary and adjacent shelf ecosystem: trophic structure, biomass flows and the role of fisheries
Gasalla et al – Ecosystem model of the Santos Basin Marine ecosystem, SE Brazil
Opitz & Garilao – Impact of Commercial Fisheries on the Marine Ecosystem Within the German EEZ of the Western Baltic Sea
Ramsvatn et al – The A-lex project: Environmental effects of increased shipping in the Arctic- a case study for the Pechora Sea
Carvalho & Angelini – Fisher’s consulting and biological evidence to probe loss of fish diversity in a tropical coastal lagoon
13:30 – 14:30  Lunch
14:30 – 18:00  Session 2 – Informing and planning marine conservation
Chairs: L. J. Shannon (UCT, South Africa), Chiara Piroddi (JRC, Europe)
14:30  Keynote lecture by Dr. Tony Pitcher:
Marine protected areas in the Haida Gwaii ecosystem (Canada): modelling and
policy issues

Oral presentations

15:00 Wolff & Taylor – Simulating the combined effect of El Nino and the ban of the industrial fishery on the Galapagos Marine Reserve – an exploratory analysis using EwE

15:15 Barrier et al – Assessing the trophic functioning of the marine protected area of Portofina (Italy) with a standardized ecosystem model

Coffee break

16:00 Valls et al – Keystone species: a restored and operational concept to inform marine biodiversity conservation

16:15 Eddy et al – Trade-Offs between Invertebrate Fisheries Catches and Ecosystem Impacts in Coastal New Zealand

16:30 Rehren & Wolff – Modelling the Multispecies Fishery of Chwaka Bay, Zanzibar – Basis for Exploration of Use and Conservation Scenarios

16:45 Daskalov et al – Modelling spatial effects of illegal fishing in the north Caspian sea ecosystem

17:00 Morato et al – Deep-sea ecosystem model of the condor seamount

17:15 Fetzer – Implementing the Habitat Directive in Germany: case conventions versus Ecopath, Ecosim & Ecospace

17:30 Gruner – Effect of marine protected areas and fishing on population biomass of five species of Serranidae in La Paz Bay, Mexico: an Ecospace study

Poster presentations

17:45 Coll & Steenbeek – New software plug-in to calculate biodiversity and conservation-based indicators from Ecopath with Ecosim food web models

17:45 Prato et al – Towards a balance between complexity and feasibility in food-web models of Mediterranean coastal ecosystems: addressing uncertainty while accounting for data collection constraints

18:00 Bourdaud et al – Using models, to assess ecosystem indicators and define targets of the good environmental status.

18:00 Arriagada & Neira – Analysing the collapse and lack of recovery of the two Nototenid stocks in the Antarctic peninsula (Sub area 48.1)

18:00 Lercari et al – Trophic models in the Southwestern Atlantic Ocean: evaluating structure and functioning of coastal ecosystem

Poster session and welcome reception
DAY 2: TUESDAY 11TH NOVEMBER

_Master of Ceremony: Simone Libralato (OGS, Italy)_

08:00 – 09:00  Registration
09:00  Opening by Master of Ceremony
09:00 – 13:00  Session 3 – Ecosystem evolution and challenges for management
    Chairs: Didier Gascuel (Agrocampus, France), Sebastian Villasante (University Santiago de Compostela, Spain)
09:00  Keynote lecture by Dr. Ken H. Andersen: Conflicting objectives for ecosystem based fisheries management
09:30 – 12:15  Oral presentations
    09:30  Bevilacqua et al – Beyond anecdotal information: the use of fishers’ knowledge to model fisheries
    09:45  Hernandez-Milian et al – The importance of locally specific data in Ecopath models
    10:00  Bentorcha et al – EcoTroph to assess changes in marine ecosystems – Application to the Bay of Biscay and Celtic sea case study
    10:15  Kumar et al – Simulation of zebra mussel invasion and evaluation of impacts on the Mille Lacs Lake, Minnesota: An ecosystem model
10:30 – 11:00  Coffee break
11:00  Surma et al – Whaling, primary productivity and the changing structure of the Southern Ocean food web
11:15  Heymans & Tomczak – Regime shifts in the Northern Benguela, challenges for management
11:30  Lam & Pitcher – Niche Construction Theory and Ecosystem Stanza Modelling: Northern BC Fisheries
11:45  Zetina-Rejón et al – The relevance of cohesive structures in the self-organization of marine ecosystems
12:00  Colléter et al – A meta-analysis of ecosystems’ trophic functioning: identification of typical trophic behavior and associated responses to fishing impact
12:15 – 13:00  Poster presentations
    Abdou et al – The use of Ecospace model as a simulation tool for fisheries management plans: case of the Gulf of Gabes
    Arreguín-Sánchez et al – Developing scientific capacities through international collaboration for ecosystem-based management of marine resources facing climate change: Mexico, Uruguay and Colombia
    Arreguín-Sánchez et al – Ecosystem changes and “ecosystem limit reference level” for sustainable fisheries: the Campeche Bank Mexico as study case
    Bayle-Sempere et al – An ecosystem approach to the role of fish farming in coastal areas
    Bezerra et al – Wasp-waist control on food web of a tropical freshwater reservoir
    Akoglu et al – A comparative analysis on the ecosystem structure and functioning of four regional seas of Turkey (Black Sea, Marmara, Aegean and the Mediterranean)
    Hernández-Padilla et al – Management of aquatic ecosystems exploited by adaptability and sustainability: the case of fisheries in Sinaloa, Mexico
    Leite Lima et al – Using the Ecopath to simulate impacts on rivers
    Neira et al – Analysing the ecological role of Falkland sprat (_Sprattus fueguensis_) in the inner sea of southern Chile
    Piroddi et al – Modelling the Mediterranean marine ecosystem as a whole: addressing the challenge of complexity
    Saygu et al – Modelling impacts of fishing on trophic energy flow in Mersin Bay, Northeastern Mediterranean
    Tierney et al – Modelling the Bioaccumulation of Sellafield-derived radiocarbon (14C) in the Marine Environment
List of Poster Presentations

Xavier et al – A Trophic Model for Mamanguape Mangrove Estuary (Northeastern Brazil) confirms the prominence of detritus role

13:00 Group photo
13:00 – 14:30 Poster sessions and lunch
14:30 – 18:00 Session 4 – Modelling cumulative ecosystem dynamics
   Chairs: Marta Coll (IRD, France), Sheila Heymans (SAMS, UK)
14:30 Keynote lecture by Dr. Sheila Heymans & Dr. Marta Coll:
   Modelling cumulative ecosystem dynamics: progress and challenges
15:00 – 17:30 Oral presentations
15:00 Pedersen et al – Ecopath modelling of a subarctic Norwegian fjord after a decline in the coastal cod (Gadus morhua) stock and invasion of red king crab (Paralithodes camtschaticus)
15:15 Zhu et al – Ecotrophic modeling of anthropogenic cumulative impacts on the sustainability of fisheries productions: comparison of Lake Erie and Great Slave Lake ecosystems
15:30 – 16:00 Coffee break
16:00 Lozano-Montes et al – Evaluating the ecosystem effects of variation in recruitment and fishing effort in the western rock lobster fishery
16:15 Tecchio et al – Comparative ecological analysis of Mediterranean deep-sea ecosystems and simulations of global change
16:30 Caccin et al – Marine food webs and warming scenarios: modelling a thermophilic species invasion
16:45 Christensen et al – Representing variable habitat quality in a spatial food web model
17:00 Piroddi et al – Advances on modelling spatial-temporal ecosystem dynamics in the Mediterranean Sea
17:15 Pethybridge et al – Biochemical tracer techniques and their utilization in ecosystem models
17:35 Poster presentations
   Reyes-Martinez et al – Trophic functioning of sandy beaches with different degrees of human disturbance
   Inoue et al – Temporal and spatial variability in overfished coastal ecosystems: a case study from Tango bay, Japan
   Corrales et al – Ecosystem structure and fishing impacts in the NW Mediterranean Sea using a food-web model within a comparative approach
   Corrales et al – Modelling the alien species impacts in marine ecosystems
   Gal et al – Dessim: a decision support system for the management of Israel’s Mediterranean exclusive economic zone (EEZ)
   Tomczak et al – Ecological network indicators of ecosystem status and change in the Baltic sea
   Tecchio et al – Modelling trophic flows in the seine estuary: comparison between habitats with contrasting impact
   Astorg et al – Shifting states of a Mediterranean food web evidenced by ecological network analysis
   Nascimento et al – Potential impacts of global changes on a Brazilian continental shelf and slope communities
   Camargo et al – Assessing the impact of hydroelectric dams on Amazonian rivers using Ecopath with Ecosim: a case study of the Belo Monte dam
   Coll et al – Cumulative effects of environmental and human activities in the southern Catalan Sea ecosystem (NW Mediterranean) associated with the Ebro river delta
   Simons et al – Gulf of Mexico species interactions (gomexsi): integrated ecosystem trophic data for Ecopath models and ecosystem based fisheries management
DAY 3: WEDNESDAY 12TH NOVEMBER

Master of Ceremony: Chiara Piroddi (JRC, Europe)

08:00 – 09:00 Registration
09:00 Opening by Master of Ceremony
09:00 – 12:30 Session 5 – End-to-End modelling
Chairs: Simone Libralato, Ekin Akoglu (OGS, Italy)
09:00 Keynote lecture by Dr. Kerim Aydin:
Ecopath and Ecosim in fisheries management: notes from two decades on the front lines
09:30 – 12:30 Oral presentations
09:30 Christensen et al – The global ocean is an ecosystem: Simulating marine life and fisheries
09:45 Paves et al – Trophic impact and keystone species in the two pelagic communities in the North Chilean Patagonian coastal system
10:00 – 10:30 Coffee break
10:30 Bundy et al – Modelling the potential effects of climate change on the Western Scotian Shelf ecosystem, Canada
10:45 Steenbeek et al – Bridging the gap between ecosystem modelling tools and geographic information systems: driving a food web model with external spatial-temporal data
11:00 Ruzicka et al – An intermediate complexity, physically coupled end-to-end model platform for coastal ecosystems
11:15 Akoglu et al – Two-way coupling of EwE in Fortran with an intermediate complexity NPZD model
11:30 Bulman et al – EwE models in Australia
11:45 Lewis et al – Using Ecopath with Ecosim and Ecospace to model the response of estuarine nekton to multiple habitat restoration scenarios in Barataria Bay, Louisiana, USA
12:00 Ofir et al – Managing Lake Ecosystem by using a food-web model – Lake Kinneret as a case study
12:15 Taylor & Wolff – Towards an ecosystem approach to fisheries in the Northern Humboldt Current System
12:30 – 12:45 Poster presentations
Pavés et al – Carbon fluxes of the two pelagic communities in the North Chilean Patagonian coastal system
Alexander et al – Modelling the potential benefits of marine renewable energy installations
12:45 – 14:00 Poster sessions and lunch
14:00 – 17:30 Session 6 – What next?
Villy Christensen (UBC, Canada), Marta Coll (IRD, France)
This session will be an open discussion with participants to the conference about ideas and suggestions for the future of the EwE approach and the field of ecological modelling.
14:15 – 15:00 Poster presentations
Lucey et al – Improving the EBFM Toolbox with an Alternative Open Source Mass Balance Model
Colléter et al – EcoBase: a repository solution to gather and communicate information from EwE models
Colléter et al – Overview of worldwide applications of the Ecopath with Ecosim approach using the EcoBase models repository
Steenbeek et al – Programming with EwE: customizing EwE for your science
The Executive Board of the Ecopath Consortium et al – The Ecopath Research and Development Consortium: the future of EwE
15:00 Open discussion
15:30 – 16:00 Coffee break
16:00 Open discussion (continued)
17:30 – 18:00 Closure of the Conference
KEYNOTE SPEAKERS

VILLY CHRISTENSEN
Dr Villy Christensen is a professor and co-director at the Fisheries Center, University of British Columbia and director of the Global Modelling group. He works with ecosystem modeling and has a background in fisheries research. His research has since 1990 been centered on understanding impacts of human exploitation on marine ecosystems. He has been central to the development and dissemination of the Ecopath approach and software, a tool for ecosystem modeling. Ecopath modeling has become the de-facto standard for ecosystem approaches to fisheries management, and is being applied throughout the world. Through cooperation with scientists worldwide, he has focused on trophic dynamics of aquatic resources. He has led a large number of training courses and workshops throughout the world, centered on developing ecosystem approaches to fisheries management.

STEVE MACKINSON
Dr Steve Mackinson is a scientist at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS, UK). At CEFAS, he has been involved in Ecopath with Ecosim modeling and study of trophic transfer efficiencies in food-webs of North Sea. He has also worked on issues of model complexity and effects of model structure for the Ecopath and Ecosim modeling approach. Dr Mackinson’s research efforts also extend beyond the strict ecosystem modeling specialty into socio-economic drivers of fisheries management. He has worked on perceptions of the fishing industry and has elucidated measures to bridge gaps between science and stakeholders.

TONY PITCHER
Dr Tony Pitcher is a professor at the Fisheries Center, University of British Columbia and the director of the Policy and Ecosystem Restoration in Fisheries research group. His current research addresses three aspects of fisheries ecology: 1. The history and analysis of the impacts of fishing on aquatic ecosystems, and how future policy may use this information to foster sustainability and the reconciliation of biodiversity with human benefits; 2. The development of quantitative, multi-criteria evaluation frameworks and rapid appraisal techniques for assessing the status of fisheries, management instruments and management goals in a scientific, evidence-based and replicable fashion; and 3. A predictive understanding of how fish shoaling behavior impacts fisheries. His research has taken him throughout Africa, Europe, Asia, Australasia, and Latin America.

KEN H. ANDERSEN
Dr. Ken H. Andersen is a theoretical physicist working with marine ecology. Ken wants to understand how life in the ocean is organised, why marine organisms look and act the way they do, and how marine ecosystems react to perturbations like fishing, species removals/invasions or climate change. More specifically Ken works on: trait-based models of life in the ocean (see http://www.oceanlifecentre.dk), size-structured models of marine ecosystems (see https://www.stockassessment.org/spectrum), and fisheries induced evolution.”.

JOHANNA J. HEYMANS
Dr Johanna J. Heymans is a lecturer with the Ecology Department of the Scottish Association for Marine Science (SAMS, UK). She has worked extensively with Ecopath with Ecosim and Ecological Network Analysis and is very interested in the use of these tools for marine spatial planning as well as ways to combine ecological and social network analysis for ecosystem based management. Previously she worked at the Fisheries Centre on several ecosystem models for the east and west coast of Canada, the decline of Steller sea lions and a historical reconstruction for the Bird’s Head functional seascape in Eastern Indonesia.

MARTA COLL
Dr Marta Coll is a researcher from the Institut de Recherché pour le Développement, at the Marine Exploited Ecosystems mixed research unit (EME 212 UMR - IRD, University of Montpellier II and
Ifremer) in Sète (France). Her research focuses on understanding patterns and processes that characterize marine ecosystems and, in particular, changes of, and threats to, marine biodiversity. She studies population, community and food-web dynamics linked with human activities (such as fisheries, climate change, eutrophication, and invasive species), and how these translate into changes in ecosystem structure and functioning, and services that humans obtain from the ocean. She develops and applies a variety of ecological analyses such as ecosystem modelling techniques and statistical tools, and uses historical data, fisheries statistics, experimental results and field data sets.

KERIM AYDIN

Dr. Kerim Aydin is a Research Fishery Biologist, at the NOAA Fisheries, Alaska Fisheries Science Center (USA). His research is focused on modeling predator/prey interactions, both from an individual behavioral standpoint and from a population (food web model) standpoint, on developing data collection techniques for examining marine food webs (e.g., diet studies and stable isotope examinations of fish communities), and on applying these models in a fisheries management context. He is particularly interested in the stability and complexity of large marine food webs and how structural elements of marine food webs evolve in response to climate variation. He received his PhD in 2000 from the University of Washington, School of Aquatic and Fishery Sciences.
A EUROPEAN PERSPECTIVE ON MODELLING TO SUPPORT AN ECOSYSTEM APPROACH TO MANAGEMENT ¹

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ABSTRACT
Recent EU legislation makes explicit the need to take trophic interactions and marine environmental impacts into account in management. Policy requirements are echoed in the ICES strategic plan, where an integrated and ecosystem approach will form the basis for delivering scientific advice. Together, these commitments signal a clear need for ecosystem modelling tools to prove themselves worthy of providing evidence on the effects of trophic interactions that can be used with confidence in advice. It’s a daunting but well-timed challenge. Achieving this requires having a strategy to guide the development and use of models for advice, and convincing demonstrations of their utility. Various tools will be required to meet the needs of supporting stock assessments and assessing ecosystem and fishery impacts. Bringing their results together to generate an integrated understanding and communicate it clearly is an important challenge. The shift in the skill sets being required for generating advice requires investment in training and development.
REDUCING ANTHROPOGENIC IMPACTS ON NIGERIAN COSTAL FISHERIES RESOURCES

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ABSTRACT

Historically, Nigeria has produced from 25,000 MT to 323,200 MT of fish annually (1950-2006). This amount of fish production meets only a fraction of the animal protein needs of a growing population of 175 million. Although imports have bridged the shortfalls in supply of fisheries resources, high demand for these resources has implications for overexploitation of marine and coastal resources. In addition to heavy exploitation of marine resources, other anthropogenic stressors in the coastal ecosystems include petroleum hydrocarbon pollution, and habitat degradation due to the close proximity of megacities such as Lagos and Africa’s largest hydrocarbon extraction industry in the Niger Delta. More recently, effects of overfishing in the industrial fishing subsector may have been ameliorated due to a release of fishing pressure caused by accessibility issues.

The most important ecological issues are: (1) habitat degradation arising from nutrient enrichment and land reclamation from the sea in coastal cities. (2) Severe environmental pollution in the Niger Delta (an important nursery area for a variety of marine and brackish water species) caused by direct discharge of petroleum hydrocarbons into estuarine habitats and oceanic waters, (3) Large scale artisanal fisheries with approximately 100,000 small fishing units employing low to medium technologies to exploit fish resources in 850 km stretch of coastal waters, and (4) Intensification of industrial shrimp trawling from the mid 1980s - 2000s when landing far outstripped prediction from shrimp resource potential in the Gulf of Guinea coastal surveys of the 1960s. A more recent development for the industrial fishing subsector is restriction of access to important fishing grounds due to safety concerns caused by unrest in the Niger Delta.

An ecosystem approach is proposed using the Ecopath with Ecosim software to answer the following questions: How is recruitment impacted by loss of habitat through sea reclamation and oil pollution? How has waste generated from coastal cities impacted the quality of coastal waters and their ability to support important fisheries? How do high densities of fishing canoes impact coastal fisheries? How are these multiple factors interacting to drive observed patterns and processes in Nigeria’s coastal ecosystems? What strategies are required to safeguard coastal resources so they can continue providing the important ecological and economic services they have traditionally provided? To address these questions, we (1) build a food web model for Nigerian coastal waters and account for fisheries, (2) model impacts of habitat loss, (3) traces contaminants through the marine food web, and (4) explore management alternatives for the fisheries and hydrocarbon extraction industries.

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Scientific advice for management


DYNAMIC SIMULATION MODEL OF ILLEGAL FISHING GEAR REMOVALS IN THE DANAJON BANK, CENTRAL PHILIPPINES

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ABSTRACT

The northern section of the Danajon Bank in the Central Visayas, Philippines is a shallow, tropical reef system that supports a multi-gear, multi-species fishery, which is primarily artisanal and subsistence in nature. At the same time, illegal fishing gears that are deemed destructive by either their manner of operation (e.g. blast fishing, fishing using cyanide and other noxious substances, bottom seining) or technical design (e.g. use of fine mesh netting) continue to operate and are seemingly able to evade the local fishery law enforcement. In this study, we used a dynamic simulation model, Ecosim, to explore the ecological and socio-economic impacts of a hypothetical successful ban on the illegal fisheries in the Danajon Bank. Two main scenarios were compared: one whereby the displaced illegal fishers were reallocated to the remaining legal fisheries, and another without a reallocation of displaced fishing effort. For both scenarios, we calculated the relative increments of the biomasses of living groups, harvests and catch values, and corresponding net profit and employment. The simulations yielded varying types and magnitudes of system response, with strong implications on the underlying food-web dynamics. Foremost, the study demonstrated that the value of fishing effort reduction lies not in the resulting dramatic changes in overall harvestable biomass but in effecting discrete biomass changes across the trophic strata. In this regard, all simulations of illegal fishery removals resulted in relative increases in predator group biomasses that subsequently resulted in direct and indirect top-down trophic responses. Conjointly, simulated increases in overall system biomass did not necessarily translate to expected increases in overall yields and profits, but showed noteworthy impacts at the per capita level of specific fishing operations. The magnitude and direction of change likewise varied for the scenarios with and without the fishing effort reallocation. We therefore advocate the exploration of other alternative fishing effort reallocation scenarios with a focus on per capita yield and profit incomes analysis against the overall gains of the fishery, both at the short- and long-term. These provide useful insights that are relevant to informing policy for the management of small-scale and subsistence fisheries.

ACKNOWLEDGEMENTS

We thank all the field data collectors, FISH Project staff, and the local community members who helped considerably in the data collection and consolidation. We likewise thank Prof. Nygiel Armada, the senior fisheries adviser of the FISH Project and Prof. Wilfredo Campos of the University of the Philippines for their invaluable inputs and comments to developing the work. This research was supported in part by the DAAD-Scholarship Programme “Postgraduate Degree Courses with Relevance to Developing Countries”.

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Bacalso, R.T.M., Wolff, M., (in press). Trophic flow structure of the Danajon ecosystem (Central Philippines) and impacts of illegal and destructive fishing practices. 10.1016/j.marsys.2014.05.014.


THE IMPACTS OF CHANGES IN PRAWN TRAWLING EFFORT ON TROPHIC STRUCTURE AFTER ESTABLISHMENT OF A MARINE PARK

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ABSTRACT
The effects of trawling on structurally complex habitats and fauna have been compared to the effects of forest clear-cutting (Watling and Norse, 1999) with the growing awareness that trawling disturbance has wide-ranging impacts on the marine environment and is well known to modify benthic habitat and community structure (Jennings and Kaiser, 1998, Jennings et al. 2001, Pauly et al., 2002 and Kaiser et al., 2006). The impacts of commercial trawling include alteration of benthic environments, removal of targeted and by-catch species, and alteration of food webs; and in the recent years there has been a worldwide concern over the potential impacts of the capture and discard of non-targeted organisms by prawn trawling (Saila, 1983).

Moreton Bay is a subtropical Bay influenced by freshwater inputs from several river systems and the wetlands surrounding the Bay are protected under the United Nations Convention on Wetlands of International Importance as Ramsar Site No. 4 (Chan & Dening, 2007). The Bay supports many different fish species and hence an important area for both commercial and recreational fisheries and also supports a highly productive penaeid prawn fishery (Courtney, 1995). The Moreton Bay Marine Park (MBMP) which was established in 1993, hosts a number of threatened species such as dugongs, turtles and grey nurse sharks. A mass-balanced model of the Moreton Bay ecosystem was developed in Ecopath and was used to simulate the effects of changes in prawn trawling in the Bay before and after the establishment of the Marine Park. The scenarios were simulated using Ecosim, the time dynamic simulation module for policy exploration. The initial Ecopath model consists of 22 functional groups which include prawns and endangered species such as dugongs, turtles and dolphins. Figure 1 illustrates the trophic flows and trophic levels that represent the principal trophic interactions of the Moreton Bay ecosystem, in which each functional group is represented by a circle, with size proportional to biomass. Functional groups are illustrated by their trophic levels, ranging from 1.0 to 5.0.

The model gives an overview of the resources found in the Bay and reveals the examined ecosystem’s dynamics which are important for improving the knowledge of the structure and functioning of the Bay’s ecosystem and the ecosystem impacts of fishing. The effects of prawn trawling effort regulation and by-
catch reduction on the functional groups and their interactions were investigated and the predictions discussed in relation to the management of objectives and the future of the MBMP.

**Figure 1.** Flow diagram representing the trophic structure and biomass flow in the Moreton Bay ecosystem model. Circles represent the functional group and horizontal lines show the trophic level.

**ACKNOWLEDGEMENTS**

We acknowledge the University of Queensland for support.

**REFERENCES**


ANALYZING RECOVERY IN THE MAIN DEMERSAL STOCKS FROM SOUTHERN CHILE IN A MULTISPECIES CONTEXT

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ABSTRACT

The main demersal stocks supporting Chilean trawling and longline fisheries are either overexploited or collapsed. That is the case of southern hake (Merluccius australis), hoki (Macruronus magellanicus) and kingklip (Genypterus blacodes), among others. Therefore, recovery strategies for overexploited and collapsed stocks are required and are now mandated by the new Chilean Fishery and Aquaculture Law Nº 20657, promulgated in 2013, which establishes that the target biological point must be the maximum sustainable yield (MSY). In this context, total annual allowable catch (TAC) in these stocks have been set for 2014 considering to reach a target spawning biomass B40% (default 40% of unfished biomass) and fishing mortality rate (F) which result in an equilibrium biomass level equal to B40%, being used F45% as a proxy of FMSY. These catch levels are estimated under single-species considerations only. However, the Chilean fisheries based on demersal stocks are multifleet and multispecific with strong predator–prey relationships between fishing resources such as southern hake, hoki, southern blue whiting, as well as cannibalism. Therefore, our objective is to evaluate whether applying single-species MSY policy in southern hake, hoki and blue whiting is successful when the multispecies/food web context is taken into account.

To accomplish the above, we built a model representing the food web in southern Chile (41° 28´S - 57°S). The model considers 12 functional groups from phytoplankton to top predators. However, the model is focused in the interactions among fishing resources. The modeling framework is the Ecopath with Ecosim (EwE) software (Walters et al. 1997). The model was fit to time series of biomass (B) for the main fish stocks for the period 1990 to 2012, using time series of fishing mortality as forcing factor. To attain the better fit was used the Monte Carlo approach included in EwE. With this approach, 500 trials of parameter-combinations were tried until a balanced Ecopath model compose for a parameters combination which minimize the sum of squares (SS) was achieved. In addition, an evaluation of both the sensitivity of SS to vulnerability parameter and changes in model primary production were required to improve the overall fit. Data source corresponds to Chilean official statistics for the main fisheries (see www.subpesca.cl; www.fip.cl; www.ifop.cl). Later, we projected the biomass of southern hake, southern blue whiting and hoki from 2013 to 2022 under scenarios with different levels of F like: 1) a scenario of biomass trends for each stock under FMSY, while keeping current fishing mortalities for all others fishing
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resources; and 2) a scenario in which all three stocks are fished at FMSY at the same time. The values of the target fishing mortality rate (F45%) and target spawning biomass (B40%) used for the three stocks in southern Chile are: southern hake F45% = 0.236/Fcurrent = 0.37/B40% = 185040 ton; hoki F45% = 0.173/Fcurrent = 0.186/B40% = 354600 ton; blue whiting F45% = 0.336/Fcurrent = 0.02/B40% = 359938 ton.

The results show that the fit of EwE estimates to observed biomasses from 1990-2012 are acceptable in southern hake, kingklip, blue whiting (Micromesistius australis) and hoki (Figure 1). The initial value of SS was 13,180, but after using routines for minimization of SS the final value was SS = 2,658. In terms of the sensitivity of SS to vulnerability parameters, and therefore to the model’s residuals, the overall fit was more sensitive to the following predator-prey interactions: small pelagic fish-zooplankton, hoki–zooplankton, southern blue whiting–zooplankton and southern hake-southern blue whiting.

In the projected period (from 2013 to 2022), neither stock reached the target reference point of spawning biomass (B40%) when fished at FMSY, either independently (scenario 1) or when they all three are fished at FMSY (scenario 2), using F45% as a proxy of FMSY. Clark (2013) indicates that F45% could be used as proxy of FMSY for Chilean fisheries of demersals because F45% tracks the target B40% very closely and does better at low steepnesses than the F40% strategy. That is the reason why we selected to use the F45% proxy in ours simulations. We conclude that single species MSY might not secure stock recovery in fisheries of demersal fish stocks from southern Chile, because reference point disregards ecological interactions and therefore stock recovery could be over-optimistic under MSY approach when the multispecies/food web context is taken into account.

ACKNOWLEDGEMENTS

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JUST A FAD? POTENTIAL ECOLOGICAL IMPACTS OF TUNA PURSE SEINE FISHING ON FISH ATTRACTING DEVICES IN THE WESTERN PACIFIC OCEAN? 6

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ABSTRACT

Fisheries that target predatory species occupying high trophic levels have been shown to have negative impacts on not only the target species, but the structure and functionality of the supporting ecosystem (Pauly et al., 1998; Cox et al., 2002; Polovina et al., 2009). For example, in a subtropical Pacific ecosystem, Polovina et al. (2009) showed that the commercial pelagic longline fishery was likely responsible for a significant decrease in the abundance and mean size of primary tuna target species. This effect changed the structure of the ecosystem by freeing a trophic niche that allowed the proliferation of unmarketable bycatch species, including lancetfish and snake mackerel. Similarly, in the Gulf of Thailand, Christensen (1998) showed that the average trophic level of the ecosystem decreased from 3.35 to 3.15 over 25 years of intensive fishing. This indicated a reduction in the abundance of large fish and a progressive shift towards targeting smaller species. This process known as ‘fishing down the food web’ (Pauly et al., 1998), can result in the proliferation of species having high short life spans and rapid growth rates, and often low economic value, thus causing substantial regimes shifts in ecosystem structure (Carscadden et al., 2001; Daskalov, 2002).

Fishery scientists and managers now recognised the potential negative ecological effects of targeting single species on the overall ecosystem. Consequently, ecosystem-based fisheries management (EBFM) has become a common policy of many fisheries worldwide (Scandol et al., 2005). Fisheries targeting species that occupy high trophic levels may be more susceptible to breaching such policy, and therefore, need to be given close attention in assessing their broader ecological impacts.

The Warm Pool oceanographic province in the western Pacific Ocean is defined by the 28° C sea surface temperature isotherm, covering over 181 million km2. It supports the largest and most valuable tuna fisheries in the world that capture a range of high trophic level species using pelagic longline, pole-and-line, and purse seine either unassociated (PSU) or in association with (PSA) natural or artificial floating objects, or Fish Attracting Devices (FADs). In particular, these fisheries target bigeye and yellowfin tunas, skipjack, swordfish and albacore. In recent years, the increased efficiency and catches made by the PSA fishery has raised concerns over the sustainability of bigeye, yellowfin and skipjack tunas, since their juvenile often aggregate in the vicinity of floating objects (Leroy et al., 2013). Furthermore, the increased PSA effort has dramatically increased the catch of non-target species. Although this has seen to be beneficial in some respects by opening new markets for edible bycatch species (e.g. dolphinfish, wahoo and rainbow runner), it raises serious concerns by fishery managers over the long-term sustainability of more vulnerable species with less productive life histories, such as sharks and billfish (Taquet, 2013).

The objective of the present study was to build an Ecopath ecosystem model of the Warm Pool ecosystem to explore the potential effects of purse seine fishing on ecosystem structure and functionality, as well as direct changes in the biomass of individual target and bycatch species. The year 2005 was chosen as the reference year to model the trophic flows in the Warm Pool in the Ecopath model, since this period coincided with an extensive dietary study of pelagic fishes by the SPC Oceanic Fisheries Programme. The Warm Pool ecosystem was represented as 44 functional groups, with the primary target species being disaggregated into juvenile and adult life stanzas. The SPC coordinate a scientific observer program for WCPO pelagic fisheries, and from 1995 included monitoring of bycatch species. Coupled with data from age-structured stock assessments for the principal species, the addition of bycatch time series permitted extensive Ecosim model calibration using 111 time series of biomass, fishing mortality and catch trends for 37 of the 44 ecological functional groups. Ecosim simulations were then undertaken to investigate the potential impacts of fishery management strategies of changing the 2013 PSA effort by +/- 50% or 100% and observing the ecosystem and species biomass responses 10 and 30 years later.

Ecosystem indicators (Fishing in Balance, Kempton’s Q, and Mean Trophic Level of the Catch) showed the Warm Pool ecosystem changed considerably since the early 1970s due to the cumulative impacts of increasing effort in the four pelagic fisheries. The indicators showed an expansion of the fishery, which resulted in a slight increase in the average trophic level of the catch due to increase catch of high trophic level bycatch species, such as sharks and billfish. However, diversity and biomass of the ecosystem comprising trophic level 3 and greater has been diminished.

Simulated changes to PSA effort resulted in only modest changes (<10%) in the biomass of functional groups directly interacting with the fishery. There was little evidence that PSA or PSU fishing would cause significant disruption of the ecosystem integrity in the short term by causing trophic cascades, since the impacts of most fishery simulations did not propagate lower than a trophic level of 3.

The most important results from PSA simulations was that increases in effort caused the greatest biomass declines in longer-lived bycatch species, namely Silky and White tip sharks. Conversely, decreases in PSA effort resulted in reciprocal increases in biomass of these species and a negative effect on their prey biomass, which were generally target species of the PSA fishery (i.e. bigeye and yellowfin tuna). Therefore, this presents fishery managers with a complex trade-off where conservation and fishery profitability need to be balanced. These results demonstrate the value of ecosystem models for disentangling some of the highly complex ecological interactions present in pelagic ecosystems, which can provide greater confidence in developing EBFM strategies that may achieve the long-term sustainability of species populations and fishery profitability.

ACKNOWLEDGEMENTS
The authors thank NZ AID, SPC and the CSIRO for funding the development of the Ecopath model.

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**DIAGNOSIS OF THE ECOSYSTEM IMPACT OF FISHING AND TROPHIC INTERACTIONS BETWEEN FLEETS: A MAURITANIAN APPLICATION**

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**ABSTRACT**

Based on the Mauritanian case study, this presentation shows how the EcoTroph model (Gascuel et al., 2011) can be used to build global diagnosis of the ecosystem impact of fishing, and to analyze interactions between fleets targeting various compartments of the ecosystem. We used a preexisting EwE model, which includes 51 trophic groups and covers the whole Mauritanian continental shelf (Guénette et al., 2014). The model, initially fitted on catches and survey time series over the 1991-2006 period, was first updated based on recent stock assessment results (Meissa, 2013). Then, starting from the 2010 Ecopath model, simulations of increasing or decreasing fishing efforts were performed, using the ET-Diagnosis routine of the EcoTrophR package (Colléter et al., 2013). Multipliers of the current fishing mortality, ranking from zero (no fishing) to five (strong increase in the fishing pressure), were applied, either to the whole fisheries or fleet by fleet in order to analyse fisheries interactions (Gasche and Gascuel, 2013).

Compared to the pristine conditions, the current exploitation is estimated to lead to a 25% decrease in the total ecosystem biomass (for all animals), and to a 65% and 70% decrease for the biomass of exploited species, and top predators (TL > 4), respectively. Two indicators can be used to build a global diagnosis of the fishing impact at the scale of the entire food web (Figure 1). The E_msy indicator is the fishing mortality multiplier that allows obtaining the maximum sustainable yield of a given trophic class. Therefore, if E_msy is lower than 1, the related trophic class is overexploited (and conversely, underexploited for E_msy higher than 1). The E_0.1 indicator is commonly used in single species stock assessments, in order to define the starting point of the full exploitation (i.e. the lowest value of the fishing mortality characterised by a flat yield curve, with catch values close to MSY). Therefore, E_0.1 values smaller than 1 characterise fully or overexploited situations, while

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values higher than 1 relate to underexploited trophic classes.

These indicators show that all trophic levels higher than 4.3 are currently overfished, while those between 3.0 and 4.3 are fully exploited. In addition, trophic levels between 2.6 and 3.0 are close to full exploitation, only lowest trophic levels being currently under-exploited.

As an example, we show here results of simulations related to interactions between the industrial foreign fishery (IPF) targeting pelagics (mainly sardinella), and the small scale coastal fishery (SSCF), targeting a wide range of species including small pelagics, demersal fish and octopus (Figure 2). In these simulations, other fleet segments (i.e. industrial demersal fisheries) remained constant. Results demonstrated the strong interactions between the two fisheries. An increase in the fishing effort of the industrial pelagic fishery would lead to an increase in total catch but to a significant decrease in the whole ecosystem biomass, in the catch of the small scale fishery, and in the mean trophic level of ecosystem biomass and catches. The impact results from both direct and indirect effects, because the industrial pelagic fishery targets species that also targeted by the small scale fishery and prey for demersal fish exploited by the small scale fishery.

Conversely, increasing the fishing effort of the small scale fishery would have limited quantitative impacts (on the whole ecosystem biomass and catch) and limited qualitative impacts (on mean trophic levels). Other simulations (not shown) also suggested interactions between the small scale and the industrial demersal fisheries. Each one has a limited quantitative impact on the other (i.e. on total biomass and catch), but higher qualitative impact, where increasing fishing effort would lead to a depletion in high trophic levels abundance, and therefore to a decrease in the mean trophic level of biomass and catch.

Such EcoTroph simulations finally demonstrated that fisheries management depends on highly political choices. The development of the small scale coastal fishery in Mauritania would imply to reduce the fishing effort of foreign fleets. Interactions between fleets do result not only from the target of the same species, but also from indirect effects propagating from one fishery to the other through the food web. In particular, industrial fisheries targeting small pelagics have large impacts on the whole food web, thus impacting all local fisheries.

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TOWARDS ECOSYSTEM BASED MANAGEMENT OF THE AZORES MARINE RESOURCES

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ABSTRACT
The European Marine Strategy Framework Directive intends to adopt an ecosystem-based management for resources, biodiversity and habitats that puts emphasis on maintaining the health of the ecosystem alongside appropriate human use of the marine environment, for the benefit of current and future generations. Within the overall framework of ecosystem-based management, ecosystem models are tools to evaluate and gain insights in ecosystem properties and functioning. In this talk, an Ecopath with Ecosim and Ecospace model for a North-Atlantic deep-sea ecosystem was developed to conduct simulations to explore and, when possible, to quantify the effects of the new Common Fisheries Policy regulations in the Azores ecosystem; to examine management questions such as the impact of fishing on vulnerable habitats; to examine the use of no-take areas to explore their role in ecosystem based management; to explore the potential management options such as spatial zones to enhance the sustainability of commercial and recreational fisheries. The first step consisted of modeling the flows and biomasses of the Exclusive Economic Zone waters of the Azores using appropriate data on biology and fisheries, with preference to local data. A total of 45 functional groups, including a detritus group, two primary producer groups, eight invertebrate groups, 29 fish groups, three marine mammal groups, a turtle and a seabird group, were modeled in this work. Cephalopods, pelagic sharks and toothed whales were identified as groups with key ecological roles in the ecosystem. In a second step, the ecosystem model for the Azores region was fitted to real data. The fitting procedure resulted in a considerable improvement in goodness-of-fit to historical and current fishing effort and biomass estimates. Optimal sets of predator-prey relationships and environmental variability were explored. This proved a big step forward in developing credible ecosystem models that can simulate the effect of different management options for the Azorean fisheries on the ecosystem. The final steps consisted of developing a fully spatial version of the Azores marine ecosystem model to explore Ecospace allows to expand spatially and to simulate different management scenarios involving spatial management.

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POTATOES OF OPPORTUNITY FOR FISHING IN THE SOUTHERN NORTH SEA

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ABSTRACT
Within the North Sea, the shallow central and southern part is distinct through the importance of flatfish and brown shrimp in species and catch compositions. Policies designed to manage fisheries for the two groups face conflicting objectives as young flatfish die in shrimpers' nets; and incentives to recover European cod may compromise yields through predation and competition.

Aside the main commercial species, bycatch and fishing of sharks, rays and turbot play a role in thinking on sustainable exploitation of the southern North Sea. Breeding seabirds as well as marine mammals may be competing with fishers for their prey. Attempts to achieve good environmental status (GES) in any of these aspects can impair fishing objectives, and may even be contradictory to other conservation efforts. As such, reducing discards means less easily accessible food for surface-feeding sea birds.

To cover these mixed-fleet and species interaction aspects, we parameterized an Ecosim model representing 60+ functional groups ranging from planktonic and benthic invertebrates via commercial species targeted by the 12 fleets embraced to sharks, rays, marine mammals and seabirds. The model was challenged with time series of biomasses, catches, fishing mortalities and efforts to ascertain plausibility of its time dynamic behaviour.

When the different fleets are subjected to a range of effort regimes, long term simulations can highlight combinations of effort levels that lead to combined yields being around the maximum possible value (the ‘potato of maximum sustainable yield opportunities’ in a multidimensional graphical representation). The simulation results can then be tested for their compliance with given reference levels of the various GES indicators deemed acceptable, creating the ‘potato of GES’. Areas of overlap between the two indicate sustainable exploitation, while failures to match suggest which trade-offs in terms of yield or conservation goals may have to be accepted.

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The research leading to the results has received funding through the MYFISH project (Maximising yield of fisheries while balancing ecosystem, economic and social concerns), a European Union’s Seventh

Scientific advice for management

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SCIENTIFIC ADVICE FOR MANAGEMENT: POSTER PRESENTATIONS

COMPARING THE MAXIMUM SUSTAINABLE YIELD OF COMMERCIAL STOCKS WITH THE ECOSYSTEM SUSTAINABILITY OF FISHING

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ABSTRACT

Despite reports of optimism in a few developed countries, most marine fisheries and exploited ecosystems around the world are in a worrisome state (Pauly et al., 2002; Froese and Proelß, 2010). Therefore, several national and international initiatives have been issued with the aim to halt degradation trends and ensure the sustainability of fisheries, such as the new European Common Fisheries Policy (EC, 2013).

One of the main goals of sustainable fisheries is to achieve sustainable levels of fish stock exploitation. To date, the sustainability of fishing is assessed on the basis of the Maximum Sustainable Yield (MSY) concept. The MSY is the theoretical largest catch that can be taken from an exploited stock over an indefinite period. The MSY permits to maintain the population at the point of maximum growth rate by harvesting the surplus production of the population, allowing the population to continue to be productive indefinitely (Hilborn and Walters, 1992). Above the MSY, density dependent factors increasingly limit breeding until the population reaches carrying capacity. The MSY-derived indicators are widely applied to guide fisheries management and MSY has been highlighted by the European Commission as a main goal to achieve under the new CFP.

However, fishing all commercial stocks at MSY levels does not guarantee the sustainability of fisheries because species in marine ecosystems interact in complex ways (Walters et al., 2005). Classic MSY

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sustainability assessments fail to take essential factors into account such as the dynamics and interactions between both commercial and non-commercial species and other drivers than fishing that affect productivity of marine ecosystems, including environmental changes.

Several integrative ecological indicators to complement single stock assessment evaluations have been proposed to address this shortcoming (Cury and Christensen, 2014). One of these indicators builds on the notion that exploited ecosystems are characterised by exports of secondary production from each fished trophic level that reduce the energy available for upper levels at the ecosystem scale, thus impinging on overall secondary production. Thus, this depletion in secondary production has been proposed as a proxy for quantifying the ecosystem effects of fishing with the Loss in Production Index (L index) as the synthesis indicator to compute this loss (Libralato et al., 2008). Based on simple ecological theories, this index has been defined taking into account both ecosystem properties (primary production and transfer efficiency) and features of fishing activities (trophic level of catches and primary production required) for quantifying the loss in total secondary production within an ecosystem due to fishing. The loss in production has been associated with the probability of sustainable fishing at the ecosystem level (Psust), thus a relationship between how much secondary production is lost due to fishing and how probable is the ecosystem to be sustainably fished permits to set thresholds on the basis of accepted risk of overfishing (Libralato et al., 2008).

For this study, the L index and Psust have been added to the computations of the Ecopath with Ecosim (EwE) ecosystem food web modelling tool (Christensen and Walters, 2004). The Ecopath and Ecosim modules and the MSY routine in EwE v6 (Walters et al., 2005) have been linked to the Lindex and Psust indicators, allowing the calculations of ecosystem dynamics, MSY and the L index and Psust to be used simultaneously to compare the outputs of a series of fisheries management simulations (Figure 1). This enables to compare both the status of single exploited stocks with the status of the whole ecosystem being exploited and evaluate the trade-offs at the different species – ecosystem level to achieve the sustainability of fisheries.

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LOOSENING THE CORSET: HOW REAL ARE WASP-WAIST ECOSYSTEMS? 11

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ABSTRACT

The concept of a wasp-waist system centres on the dominance of the intermediate trophic level (ITL) of marine ecosystems by a few species of small pelagics that funnel the biomass from plankton to predators. These species were hypothesized to exert top-down control on zooplankton and bottom-up control on their predators. We used EwE models of 17 ecosystems spanning upwelling, coastal shelves and semi-enclosed seas to evaluate the importance of wasp-waist species, other small pelagics (forage fish), and other mid-trophic level plankton consuming species. EwE are an ideal tool for this analysis since they quantify flows into, and from, the intermediate trophic levels. Our results question the very existence of the simple wasp-waist structure: the wasp-waist may not be as narrow as it was assumed originally as WW does not always dominate the biomass of ITL; wasp-waist species constitute an important prey but are unlikely to control most predators of the ecosystem; wasp-waist species are not the main predator of plankton in most ecosystems and are unlikely to exert top-down control on them. Furthermore, euphausiids and other large zooplankton play an important role in channelling zooplankton to predators directly. Wasp-waist (and forage) species are undeniably essential in marine ecosystems because of their abundance and nutritional qualities but they should be considered as part of a more integrated and complex ecosystem structure.

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HOW FISHING IMPACTS MEDITERRANEAN MARINE ECOSYSTEMS? AN ECOTROPH MODELING APPROACH

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ABSTRACT
The use of trophic models such as Ecopath with Ecosim (EwE) (Christensen and Walters, 2004) is an effective way to describe the trophic structure and functioning of the ecosystem. But comparison or meta-analyses are often difficult between models built using heterogeneous approaches, and especially using different species aggregations into trophic boxes.

In this study, the EcoTroph modelling approach (Gascuel and Pauly, 2009) was applied to five Mediterranean marine ecosystems (i.e. Gulf of Gabes, Ionian Sea, North Aegean Sea, Northern and Central Adriatic Sea and South Catalan Sea) to characterize their food webs and investigate ecosystem responses under various simulated fishing scenarios (Table 1).

Table 1. Ecopath models

<table>
<thead>
<tr>
<th>Ecosystems</th>
<th>Time range</th>
<th>Number of trophic groups</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf of Gabes</td>
<td>2000-2005</td>
<td>41</td>
<td>(Hattab et al., 2013)</td>
</tr>
<tr>
<td>Ionian Sea</td>
<td>2007</td>
<td>19</td>
<td>(Piroddi et al., 2011)</td>
</tr>
<tr>
<td>North Aegean Sea</td>
<td>mid 2000s</td>
<td>40</td>
<td>(Tsagarakis et al., 2010)</td>
</tr>
<tr>
<td>Northern and Central Adriatic Sea</td>
<td>1990s</td>
<td>40</td>
<td>(Coll et al., 2007)</td>
</tr>
<tr>
<td>South Catalan Sea</td>
<td>1994</td>
<td>40</td>
<td>(Coll et al., 2006)</td>
</tr>
</tbody>
</table>

This study presents a first attempt of using EcoTroph as common framework focused on trophic levels to compare different ecosystems through their trophic spectra of biomass, catch and fishing mortalities in the Mediterranean Sea. Based on trophic level data, this approach should lead to a better understanding of ecosystem functioning from both an ecological and fisheries perspectives in order to assess ecosystem health. Following the construction of the EcoTroph models, we described the trophic spectra of each ecosystem and we simulated the effects of an increased fishing mortality on ecosystem biomass and catch in order to analyze the sensitivity of each system.

Results highlight that the Mediterranean Sea is highly affected by the depletion of high trophic level organisms, which also appear very sensitive to fishing mortality, and that fishing impact per trophic level differs between ecosystems according to their trophic structure and exploitation patterns (Figure 1). At the ecosystem scale, different simulations of fishing mortality illustrate trophic cascades through the impact of predator biomass on their prey, which leads to subsequent biomass increase in lower trophic levels. We also noticed that ecosystems where trophic cascades were reported are less sensitive to a variation of fishing mortality. Finally, two ecosystem indicators EMSY and E0.1 were proposed to assess the level of exploitation per trophic level and to provide a diagnosis on the fishing impact at the ecosystem scale.

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CARRYING CAPACITY SIMULATIONS AS A TOOL FOR ECOSYSTEM-BASED MANAGEMENT OF A SCALLOP AQUACULTURE SYSTEM

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ABSTRACT
Over the past decade, Sechura Bay has become the center for mariculture in Peru. Here, the Peruvian bay scallop (Argopecten purpuratus) is grown in bottom cultures and the intensity and area extent of the cultivation activities have continuously increased over the years. Currently, the business involves 2500 artisanal fishermen and an export value of more than 100 million US$ per year, but activities are still expanding. For previous cultivation efforts it was shown that too high stocking densities of scallops combined with critical environmental changes may cause mass mortalities and eventually the total depletion of scallop populations (e.g. Wolff 1985; Wolff & Mendo 2000; Zhang et al. 2006; Koch et al. 2005). Accordingly, the ecosystem-based assessment of the current situation and the determination of long-term sustainable limits to scallop culture for the bay of Sechura became crucial. In order to evaluate ecosystem changes following the introduction of great amounts of scallop biomass to the bay and to estimate the long term carrying capacity of the bay for scallop culture, a bilateral German-Peruvian research project was initiated in 2012 (SASCA: Sustainability Analysis of Scallop Culture in Sechura Bay; www.sascaperu.wordpress.com). The results of this project may be applied to other coastal systems exposed to similar development by representing an ecosystem-based approach for integrated management. Monitoring data of the bay’s benthic community, harvest volumes (scallops and other fishery target species) as well as data of density and biomass of cultivated scallops and of primary production were assembled. In addition, in-situ experiments on scallop filtration and respiration rates were conducted. The ecological and physiological data were used to construct a trophic steady state energy flow model and the ecological carrying capacity was estimated by a step-wise increase of scallop’s biomass (Figure 1 and 2).

Figure 1. Flow diagram of the trophic structure of the Sechura bay system. All biomass flows in t km⁻².

Ecological carrying capacity was reached when more food was needed than produced by the system, indicated by ecotrophic efficiencies for the phytoplankton group greater than one (after Wolff 1994; Jiang & Gibbs 2005; Byron et al. 2011a,b). The model was further subjected to the following scenarios of varying conditions and the system response was explored using the EwE software: 1) Seasonal changes in primary productivity as derived from satellite data and in-situ measurements; 2) Reduction in primary productivity as measured during the strong El Niño event in 1997/98; 3) Continuous increase in cultivated scallop biomass following the trajectory of the past five years, and 4) considering the “bottleneck month”

(February) of lowest primary productivity in the bay. Results from these model explorations suggest: that a) the current magnitude of scallop bottom culture appears sustainable under environmental conditions of normal years, b) the carrying capacity of the bay for scallop culture greatly varies seasonally and inter-annually, and c) that under conditions of an El Niño induced (several months) reduction in primary productivity the bay’s carrying capacity is expected to fall below the level of current magnitude of scallop bottom culture. Carrying capacity simulations can be used to limit aquaculture growth in a responsible way (Byron et al. 2011a). In the case of Sechura bay, resulting thresholds and management scenarios are urgently needed providing a valuable tool for both local fishers and managers in their challenging task of finding sustainable long-term levels for this important socio-economic activity in Sechura Bay.

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A FOOD WEB ANALYSIS OF THE RÍO DE LA PLATA ESTUARY AND ADJACENT SHELF ECOSYSTEM: TROPHIC STRUCTURE, BIOMASS FLOWS AND THE ROLE OF FISHERIES14

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ABSTRACT

We performed an inclusive assessment of the structure and functioning of the Río de la Plata estuary and adjacent shelf ecosystem (RdLP), including the effect of fishing. A trophic mass-balance model was used to: 1) characterize the ecosystem in terms of aquatic food web theory; 2) evaluate the particular role of individual biotic components on the ecosystem (e.g. top predators, invasive mollusc species, etc.) and 3) assess the role of diverse fishing fleets on the ecosystem.

The mass-balanced model of the RdLP ecosystem is based on 37 functional groups: 3 marine mammals; one coastal birds; 17 fish; 12 invertebrates; two zooplankton; one phytoplankton; and one detritus. Fish biomass were obtained from the swept area method based on local high precision stock assessment surveys, while biomass data for most other groups (e.g. marine mammals, benthic invertebrates) were estimated by local information available in the literature. Production/biomass ratios (P/B) and consumption/biomass ratios (Q/B) were taken from the literature or obtained from the application of empirical equations, while diet composition where compiled from published information. Five fishing fleets operating in the study area were identified and categorized by base port location and country where landings took place. Uruguayan coastal fisheries comprise the industrial bottom trawl fishery, the artisanal fleet and the artisanal mussel fishery. Argentinean fleets included the northern coast of Buenos Aires fisheries and Mar del Plata fisheries fleets.

The results indicate a trophic structure and functioning common to other estuaries, where outstanding primary production exceeds consumption, and detritus accumulates in the system. This leads to distinct attributes such as high total system throughput, herbivory outweighing detritivory and an intermediate state in terms of ecosystem growth and development.

Model results showed that seabirds, sea lions (Otaria flavescens) and the Rio de la Plata Dolphin (Pontoporia blainvillei), are apex predators, with high levels of niche overlap among them, suggesting

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competition for similar resources such as fish species (Bergamino et al. 2012). Marine mammals and seabirds produce negative effects on commercially important species, while, at the same time, indirect positive effects (increase of the biomass) were also detected in some groups related to trophic cascade effects.

In addition the two invasive mollusc species affect multiple ecosystem components both directly and indirectly (Lercari & Bergamino 2011). In this sense, the gastropod Rapana venosa and the commercially valuable whitemouth croaker, Microgogonias furnieri, exhibited a high level of niche overlap (91%), while the clam Corbicula fluminea exhibited a high level of niche overlap with Mytilidae (94%), which suggests in both cases high levels of competition for similar resources. Rapana venosa had mixed trophic impacts but exhibited a predominantly top down effect on most bivalves and could could be a threat to natural resources in the area affecting to the fishing fleets. Corbicula fluminea negatively influenced phytoplankton and detritus biomass and its positive effects on higher trophic level groups suggest a central bottom-up role in the food web as a benthic-pelagic coupler. Both species had negative impacts on the five fleets modeled, showing that the effects of these invasive species could extend to the socio-economic sector.

Fisheries analyses showed widespread impacts produced by industrial bottom trawl fleets, and specific impacts produced by artisanal fisheries over important groups. The evaluation of the effects of fishing showed minor ecosystem consequence of the loss of secondary production and a high probability of sustainable fishing at ecosystem level. This study sets up the basis for temporal ecosystem level monitoring of the state of the Río de la Plata estuary and adjacent shelf ecosystem.

The model captured the main features of the RdIP ecosystem: a high production associated with low transfer efficiency from primary producers to higher TLs, significant flows to detritus and also fishing activities most likely targeting intermediate trophic groups requiring a small portion of the total available primary production.

ACKNOWLEDGEMENTS

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ECOSYSTEM MODEL OF THE SANTOS BASIN MARINE ECOSYSTEM, SE BRAZIL.\textsuperscript{15}

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**ABSTRACT**

The Santos Basin/South Brazil Bight ecosystem corresponds to the northern portion of the South Brazil Shelf Large Marine Ecosystem, characterized by the occurrence of seasonal upwellings/intrusions and oceanic mesoscale vortex formation. Trophodynamics is mainly based on pools of primary production and detritus-based pathways with high biodiversity richness, and regular fisheries removals. In fact, humans have extracted benefits to food production and livelihoods through both small-scale and industrial fisheries, with a particular emphasis on the sardine *Sardinella brasiliensis* and several shrimps target stocks that have also an important ecological role up the marine foodweb. An end-to-end description of the ecosystem was undertaken with EwE focusing on the region up to 1000 m depth, representing the early 2000-decade. The model represents the integration and synthesis of a broader effort of evaluating the Santos Basin ecosystem based on an in-depth GIS-based database funded by a national environmental licensing/mitigation program. The aim was to undertake an ecological audit of current produced knowledge on marine biodiversity based on a trophic model of 35-compartment summarizing ecosystem structure and functioning (Fig.1). With the aim of providing advice on the key scientific gaps on regional marine biodiversity useful for ecosystem-based management purposes, quantitative ecological indicators were selected based on the matrix of trophic impacts (MTI). A ranking on the importance of each compartment in terms of trophic status will be shown considering energy fluxes and biomass.

Figure 1. Schematic representation of the trophic model structure in terms of compartments and main flows of the Santos Basin marine ecosystem.
IMPACT OF COMMERCIAL FISHERIES ON THE MARINE ECOSYSTEM WITHIN THE
GERMAN EEZ OF THE WESTERN BALTIIC SEA

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ABSTRACT

Fisheries belong to the strongest negative anthropogenic interventions on marine ecosystems (Jones 1992, Hall et al. 2000, and Kaiser et al. 2006). In Europe, this is particularly true for the North and Baltic Sea and therefore also for the German Exclusive Economic Zone (EEZ) of both seas.

In the scope of the project “ecosystem based fisheries management in the German EEZ” implemented by the German Federal Agency for Environmental Protection (Bundesamt für Naturschutz BfN) impacts of commercial fisheries on the marine ecosystem in the German EEZ of North and Baltic Sea, with special emphasis on NATURA 2000 areas are being studied with the use of trophic network models. Model results offer suggestions for sustainable fisheries management measures according to article 2.3 of the new Common Fisheries Policy (CFP) of the European Union (EU) for implementation of “an ecosystem based approach for fisheries management by minimizing the negative impacts of fishing activities”.

For the south-western Baltic Sea a trophic network model has been constructed representing the following geographical regions: Great Belt, Little Belt, Kiel Bay, Bay of Mecklenburg, Arkona Basin until West of Bornholm Basin (ICES subdivisions 22 and 24) and including all NATURA 2000 areas in the German EEZ (see Fig. 1). NATURA 2000 areas in the German EEZ comprise Fehmarn Belt, Kadetrinne, Westliche Rönnebank, Adlergrund and Pomeranian Bay with Oderbank, while Pomeranian Bay is also a designated EU bird protection area (see Fig. 1).

The modeling software Ecopath with Ecosim (EwE www.ecopath.org) was used for model preparation. FishBase (www.fishbase.org), SeaLifeBase (www.sealifebase.org), ICES database, ICES Stock_Summary, DATRAS, BfN clusters 4 and 6, published models, and other relevant literature (e.g. Froese & Sampang 2013, Opitz 2007) served as data sources. The model for the Western Baltic Sea represents the following 24 trophic groups: Seals (Phoca vitulina, Halichoeres grypus), (sea-) birds, harbour porpoise (Phocoena phocoena), cod (Gadus morhua) 3+ years, 2 years, < 2 years, flounder (Platichthys flesus), dab (Limanda limanda), plaice (Pleuronectes platessa), turbot (Scophthalmus maximus), other demersal fish, herring (Clupea harengus) >2 years, <2 years, sprat (Sprattus sprattus), other pelagic fish, pelagic macrofauna (jelly fish), benthic macrofauna, mesozoooplankton, microzooplankton, benthic meiofauna, bacteria/ microorganisms, phytoplankton.

Figure 1. Area represented by the fishery model: South-Western Baltic Sea with German EEZ (green line), NATURA 2000 areas (white) and ICES subdivisions 22 and 24 (red line).

benthic producers, detritus/DOM. The model aims to analyze impact of fisheries on the marine ecosystem of the western Baltic Sea with focus on the interaction (diet competition, cannibalism) of the main commercial target species cod, herring and sprat.

Other questions to be answered by the model are: Which ecosystem-based fisheries management provides for the economically most important species in the German EEZ and the German NATURA 2000 areas of the Baltic Sea a) the highest catch b) with the highest profit, and c) with the least negative impacts on the ecosystem as specified by the CFP (F<Fmsy) and the Marine Strategy Framework Directive (MSFD) (B > Bmsy, healthy size and age structure of the stocks, no impacting of other species)? Note that a) and b) do not have a legal basis.

The Western Baltic Sea fishery model is furthermore viewed as a supporting tool for comparing model results with stock assessments of ICES. The model serves also as a prerequisite for estimating the impact of the recently modified CFP on commercially exploited fish stocks and other elements of the ecosystem of the Western Baltic Sea. Taking into account proposals for actions for a fisheries management in NATURA 2000 areas as in Sell et al. (2011) different closure scenarios and their effects on the ecosystem are being simulated by use of the model.

For the Baltic Sea a series of predecessor models exists. All of them represent regions East of the areas where the German NATURA 2000 areas are situated. Furthermore, with one exception, all models were prepared almost exclusively with data sets from the last third of the 20th century. The preparation of updated models is thus not only of importance for the alignment of actions for ecosystem based fisheries management in the entire region of the German EEZ and particularly in NATURA 2000 areas but contributes to fill gaps of knowledge from a scientific point of view. The new model shows if - and to what extent - results of the predecessor models can be transferred to present conditions and to other regions in the Baltic Sea.

ACKNOWLEDGEMENTS

The German Federal Agency for Environmental Protection (Bundesamt für Naturschutz BfN) provided financial support, members of Clusters 4 and 6 provided necessary data for marine mammals and sea birds.

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THE A-LEX PROJECT: ENVIRONMENTAL EFFECTS OF INCREASED SHIPPING IN THE ARCTIC- A CASE STUDY FOR THE PECHORA SEA

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ABSTRACT

As the polar ice cap is retracting, shipping along the Northern Sea route is increasing. The Arctic areas are rural and sensitive and infrastructure is scarce. The A-lex project aims to assess effects of a possible oil spill in the European Arctic to support the future legislation and Norwegian foreign policy in the Arctic. Considering likely effects from oil spills, do present international regulations and standards for international shipping under MARPOL and IMO sufficiently preserve the Arctic environment and ecosystems?

The Pechora Sea (Russian Arctic) is the South-eastern part of the Barents Sea and is considered to be a separate sea area because of marked differences in environmental conditions compared to the rest of the Barents Sea. The coast of the Pechora Sea is among the most sensitive areas in the region to an accidental oil spill. The area is an important spawning ground for Arctic fishes and is rich in sea birds (e.g. ducks) and mammals (e.g. walrus) that feed on benthic invertebrates. The coastline is characterised by low-level marshes which suffer frequent and long-term flooding as well as abrasive effects of sea ice, which lies often along the muddy coasts of marine inlets and salt lakes. These muddy coasts are characterized by a high abundance of mussels, and the extensive shallow areas are susceptible to oil sinking into the ground and polluting for many years, as seen after the Florida spill (1969, Massachusetts, USA).

Through a case study of a fictitious ship wreckage where "the Oleum" has an engine malfunction and runs aground, the A-lex project describes oil spill response in Russia as well as a study of Russian legislation. "The Oleum" is a vessel type likely to be serving the future petroleum exploitation in the Arctic. To assess the environmental damage we are combining ecotoxicology and ecological modelling by using the results from ecotoxicology studies done in the laboratory (on mussels), but verified as being highly realistic after an accidental release of diesel at Skjervøy in Northern Norway, to assess effects at population level for mussels. We are integrating these results into an ecosystem model (Ecopath with Ecosim) for the Pechora Sea to make predictions on effects of a potential oil spill.

We are using the lessons learned from previous spills, such as the Prince William Sound spill (Exxon Valdez) to estimate possible effects of an oil spill on the Pechora Sea including long term effects. The ecosystem framework extends ecotoxicology from treating each species separately and restricting assessment to acute short-term impacts, to include interactions among biological components of the larger ecosystem and to longer-time series.

The A-lex project will provide a common integrated knowledge base on the political, legal, environmental and technological challenges related to Arctic shipping, exemplified by the European Arctic. The project is conducted as a co-operation between UiT-The Arctic University of Norway (faculty of law), Akvaplan-niva AS (environmental studies) and Marintek (technology for the future of Arctic Shipping).

ACKNOWLEDGEMENTS

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FISHER’S CONSULTING AND BIOLOGICAL EVIDENCE TO PROBE LOSS OF FISH DIVERSITY IN A TROPICAL COASTAL LAGOON

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ABSTRACT

In this paper, resources users were assumed as experts on environment and resources exploited. Accordingly, we focused on Fisher's Knowledge Approach (FKA) to assemble information aiming validate and complement biological data on fish community and fisheries in a tropical coastal lagoon. To achieve this, first fisher's information (as experts) was cross-validated with biological data and next their knowledge was used to justify biological findings from literature and from Ecopath model simulations using data currently sampled. The predictions assumed were that (1) fishers will claim that the peacock bass (a invasive fish species introduced) had harmful effect on fish biodiversity due to the top down control on the system; (2) the past and current food web described by fishers will match to those described by the literature and by data recently sampled and (3) experts information will support Ecopath model simulations outcomes regarding to the invasive fish species.

| Table 1. Jaccard similarity index for species richness in Extremoz Lake, based on current samplings, literature (Vieira & Shibatta, 2002 and Starks, 1913), and Fisher’s Information for Past (before 2000) and currently. |
|----------------------------------|----------------|----------------|----------------|----------------|
| Currently Sampling (CS)          | 1               |                |               |                        |
| Vieira & Shibatta (2002)         | 0.40            | 1              |               |                        |
| Starks (1913)                    | 0.20            | 0.20           | 1             |                        |
| Past Information (Fishers)       | 0.14            | 0.60           | 0.10          | 1                      |
| Current Information (Fishers)     | 0.63            | 0.37           | 0.20          | 0.10                  |

According to fishers 22 species were usually caught in the past and only 13 of these are still occurring currently. Fisher’s knowledge endorsed the presence of five marine species in the past and the current absence of marine species in the lagoon while Vieira (2002) caught 35 species (four marine) and Starks (1913) reported the occurrence of 13 species with five marine fish species (Table 1).

Current food web (Figure 2a) and past food web (Figure 2b) elaborated following fisher’s information were much simpler than the food web elaborated with data from Vieira (2002; Figure 2c). Simplest food web however resulted from current biological samplings (Figure 2d). These differences are reflected in food web metrics that reveal more paths and higher path lengths in older food webs (Table 2).
Experts indicated the collapse of fishery for commercial and subsistence purposes due to the loss of biodiversity, changes in fish species composition and simplification in trophic web, confirming biological data. Additionally fisher’s indication that the main cause for ecosystem changes was the sequential construction of bridges that interrupted water flow between the lagoon and the ocean, matched to the Ecopath with Ecosim (EwE) model simulations findings in that exotic species (*Cichla kelberi*) removal from the ecosystem does not recovery fish composition or the trophic web complexity.

**Table 2.** Food web’s metrics for the lake, based on our samplings, literature (Vieira & Shibatta, 2002), and Fisher’s Information for Past (before 2000) and currently.

<table>
<thead>
<tr>
<th>Food web’s Metrics</th>
<th>Fisher’s information</th>
<th>Biological data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Past</td>
<td>Currently</td>
</tr>
<tr>
<td>Shortest Path</td>
<td>124</td>
<td>89</td>
</tr>
<tr>
<td>Path Length</td>
<td>1.47</td>
<td>1.53</td>
</tr>
<tr>
<td>Av. no. of neighbor</td>
<td>4.26</td>
<td>3.66</td>
</tr>
</tbody>
</table>

The introduction of peacock bass was reported by 40% of fishers as the second main reason for biodiversity loss in the lagoon. Furthermore, peacock bass was associated to the trophic web unbalance by 76% of the fishers because it "eats what it sees ahead". Major control on the food web was attributed to shrimp compartment and detritus food chain, confirming model evidence that peacock bass is not forcing top down control. Fisher’s view on the role of peacock bass, enlightened simulations outcomes that never restored food web even after this top predator removal.

Results endorse that fisher’s knowledge actually is subject to bias due to the influence of local facts, personal skills, time of fishing practice and others. But these features also underscore their ability in observing and report local events and may, under certain situations, be the only source of information.

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INFORMING AND PLANNING MARINE CONSERVATION: ORAL PRESENTATIONS

MARINE PROTECTED AREAS IN THE HAIDA GWAI Ecosystem: MODELLING AND POLICY ISSUES

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ABSTRACT
An Ecospace model of the marine ecosystem around Haida Gwaii, Canada, employs detailed habitat and fisheries maps on a 4km grid deriving from extensive GIS material that is part of an official regional spatial planning process by the Haida Nation and the Canadian government. MPAs are designated by Marxan modeling and by the output of a 3-year marine spatial planning process performed by the local community. In addition to the usual biomass conservation from protected areas, results suggest considerable benefits to some fisheries from spillover around MPAs, even for quite modest amounts of protected area in the order of 10%.

Although Ecospace modeling can be very helpful in indicating likely benefits once MPAs are established, the work raises many issues in its practical application to real situations. Choice of boundaries for MPAs that are yet to be gazetted can be controversial and unfortunately many results are dependent on small local difference. Marxan output is often not usable directly for both ecological and human reasons, and similar issues apply to MPAs set by collaborative marine spatial planning. Spill-over benefits are very sensitive to values for dispersal parameters in Ecospace. This type of work not only raises fundamental issues in the governance of marine protected areas but also highlights the uncertainties inherent in even the best spatial modeling, which may be seen in public policy fora as weaknesses to question the method or even be exploited to the advantage of some stakeholders.

ACKNOWLEDGEMENTS
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SIMULATING THE COMBINED EFFECT OF EL NINO AND THE BAN OF THE INDUSTRIAL FISHERY ON THE GALAPAGOS MARINE RESERVE – AN EXPLORATORY ANALYSIS USING EWE²⁰

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ABSTRACT

The open waters surrounding Galapagos were subjected to heavy industrial fishery from the 1930s onwards. The main target species were tuna, with catches that ranged from 412 tons in 1933 to more than 23000 tonnes in 1940, but also bait species, like Sardines and Salemas were heavily exploited. During the period 1995-1997, 16 industrial fishing boats were operating around the Galapagos catching about 40,000 tons of yellowfin, bigeye and skipjack tuna. Industrial fishery was banned in 1998 with the declaratory of the Special Law for Galapagos (SLG) and the creation of the Galapagos Marine Reserve (GMR). This law allows only artisanal fishing with locally based, small boats and simple gears. Since then finfish catches have decreased greatly in the GMR to a few tens of tonnes annually. Over the last years, and after a period of mainly targeting demersal fish ( grouper) and invertebrates ( Lobster and sea cucumber) resources artisanal fishermen have started to move to the pelagic resources again with yellowfin tuna and wahoo being the target species.

In the very same year 1998, when the new law came into play and the industrial fishing was stopped, Galapagos was hit by the strongest El Nino of the past century and the GMR was impacted in dramatic ways: the thermocline deepened, the biogeographic patterning of the archipelago was homogenized and tropical warm water conditions were found everywhere. And a long-lasting (10 months) reduction in the primary productivity with an associated shift in plankton species composition caused a starving of the food web from below with drastic consequences for many biota.

We build a trophic model of the GMR of 34 functional compartments for the time period for the mid 1990s based on a diverse data set and used this reference model to explore the effect of the fishing ban and the El Nino impact on the ecosystem and its resources. We assumed a 90% reduction in the industrial fishery following the year 1998 (allowing 10% clandestine fishery to continue) and used satellite time series data of phytoplankton biomass for the El Nino period and thereafter. These data were then used to drive model behavior over time (15 years).

Our findings suggest that the El Nino-induced starving of the food web overrides the positive effect of the fishing ban for a period of 2 to 3 years, suggesting that during this period the bottom up effect of reduced primary productivity is stronger than the top-down effect from the release of the fishery. However, the disruption of the system by the El Nino impact seemed to lead to higher biomasses of large pelagic fish predators in the medium term (3-9 years), than would have occurred under the same fishery condition without the El Nino impact. It thus seems that, since predator biomass is greatly reduced during and shortly after the El Nino event, the fast growing populations of prey fish find an “open loop hole” (sensu Bakun and Weeks) to proliferate (to higher then average levels) first and are then followed by their predators in a Lotka-Volterra fashion. It then takes several years for the system to normalize. Since the residence time for the different species in the area of the GMR is largely unknown, we also explored the effect of different residence times on the biomass increase of pelagic target resources and found a substantial increase (>10%) even at residence times as low as 10%.

ASSESSING THE TROPHIC FUNCTIONING OF THE MARINE PROTECTED AREA OF PORTOFINO (ITALY) WITH A STANDARDIZED ECOSYSTEM MODEL.21

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ABSTRACT

Marine protected areas (MPAs) have been recognized as an effective tool to reduce and manage human impacts on marine ecosystems, but there are still strong gaps in knowledge on the possible consequences of protection on food web interactions. Mediterranean coastal ecosystems are complex systems that support a great diversity of habitats and species. The application of food-web modelling to these ecosystems allows to unravel such complexity and could thus help to better pursue the conservation and management objectives of Mediterranean MPAs.

Unfortunately, studies of these kind are scarce due to the difficulty of obtaining local biomass data for all functional groups in coastal protected areas of high biodiversity. In a previous work the authors proposed a standardized and simplified model structure for a coastal Northwestern Mediterranean MPA, with 31 functional groups. Here, we applied this standardized structure to model the Portofino promontory MPA, Italy (Figure 1). The model focuses on the area of major protection interest, i.e. the southern front of the protected promontory. Considerable effort has been dedicated to collect local and precise biomass data derived from the many years of research on this MPA.

This study allowed us to: 1 - Provide a snapshot of ecosystem functioning 10 years after protection, confirm the key ecological role of the top predator *Epinephelus marginatus*, (highly valued as a strong touristic attraction within the MPA) as well as identify other key species. 2. Quantify the potential export of fish biomass from the MPA to the exploited surrounding zones. 2. Test the feasibility and reliability, through extensive sensitivity analysis, of applying standardized Ecopath models centred on local biomass data, to NW Mediterranean marine protected areas.

**Figure 1.** Portofino Marine Protected Area. The modeled area encloses the area of major protection interest (black rectangle).

**ACKNOWLEDGEMENTS**

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KEYSTONE SPECIES: A RESTORED AND OPERATIONAL CONCEPT TO INFORM MARINE BIODIVERSITY CONSERVATION

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ABSTRACT

The metaphorical terminology of ‘keystone species’ was introduced in aquatic food web ecology by R.T. Paine (1969). Variations in the keystone species abundance or activity would have greater impacts on biodiversity and trophic structure, compared to other coexisting species with similar or higher abundance in the ecosystem (Paine 1969). Since Paine’s analogy, the concept of keystone species rapidly expanded, as it was applied to an ever-growing number of aquatic and terrestrial species, playing a wide variety of critical roles in the ecosystem (Paine 1995; Power and Mills 1995; Power et al. 1996). In our approach, we extricated the keystone species concept of all overlapping concepts describing other ecologically important species, and we defined a keystone species as a species characterized by a high and wide impact on its food web, despite a low biomass.

Two alternative indices measuring the potential for being a keystone species, or ‘keystoneness’ (KS), have been implemented in the Ecopath with Ecosim software (Christensen et al. 2008). The first index was proposed by Libralato et al. (2006), and the second one was adapted from a methodology proposed by Power et al. (1996). Both indices were applied to several modeled food webs, but led to inconsistent results in terms of species identified as potential keystone ones (e.g., Coll et al. 2013; Tecchio et al. 2013). In our study, we intended to explain and overcome the limitations of the existing functional KS indices.

We derived a new functional index estimating species keystoneness from a meta-analysis on a selection of food web models. 101 Ecopath models, representative of the variety of marine ecosystems worldwide, were selected with a scoring method. A suite of KS indices, comprising new and existing ones, were formulated, by combining measures of the Mixed Trophic Impact (Ulanowicz and Puccia 1990) and biomass. The 12 KS indices were applied to the 101 selected models, and the identified keystone species were recorded. Two statistical methods were used to select the new KS index: Spearman rank correlation tests and a classification tree, in which ecosystem-specific thresholds were defined.

The selected KS index was shown to be more balanced than the ones previously proposed in the literature and implemented in Ecopath, thus attributing high keystoneness to species having both low biomass and high trophic impact. Species were ranked according to their estimates of keystoneness with the selected KS index, so that potential keystone species were quantitatively identified in the 101 modeled food webs, and compared across models. Cartilaginous fishes and toothed whales obtained the highest occurrences over all models.

Keystone species, by maintaining the food web structure of their community, are critical species, which play an important ecological function, performed by few other species in the ecosystem (Perry 2010). The identification of functionally important species, such as keystone species, not only helps developing effective conservation strategies for species-level prioritization, but also better understanding ecosystem functioning and processes (Jordán 2009; Clemente et al. 2010).

REFERENCES


TRADE-OFFS BETWEEN INVERTEBRATE FISHERIES CATCHES AND ECOSYSTEM IMPACTS IN COASTAL NEW ZEALAND

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ABSTRACT

Invertebrate catches are increasing globally following the depletion and collapses of many finfish stocks (Anderson et al. 2011a; Anderson et al. 2011b), however stock assessments and management plans for invertebrates are rare. Recent fisheries research has aimed to understand fisheries impacts at the ecosystem scale, rather than traditional single-species approaches. We have employed an ecosystem modeling approach to explore the tradeoffs between invertebrate fisheries catches and their impacts on the associated reef ecosystem for an area on the south coast of Wellington, New Zealand. Fisheries for lobster (Jasus edwardsii), abalone (Haliotis australis and Haliotis iris), and urchin (Evechinus chloroticus) exist in this region, as well as traditional finfish fisheries.

We simulated exploitation for each of these groups over a range of depletion levels, from no depletion to local extinction, to estimate catches and associated ecosystem impacts, using a food web model representing the Wellington south coast, New Zealand (Figure 1; Eddy et al. 2014) and developed using the Ecopath with Ecosim (EwE) approach (Christensen and Walters 2014). In all three fisheries, the current exploitation level is estimated to be greater than that which produces maximum sustainable yield, and a reduction of current depletion of the commercial invertebrates is predicted to increase catches, with less impact on other species in the ecosystem. We found that similar catches could be made at approximately half of the present levels of depletion, which would strongly reduce ecosystem impacts. Exploitation of lobster showed the strongest ecosystem effects, followed by abalone and urchin, respectively.

Ecosystem indicators - relative abundance and keystoneness - for invertebrate groups were useful for predicting the magnitude of ecosystem impacts under exploitation scenarios. Our ecosystem approach has implications for the conservation and management of marine invertebrate resources on broader scales since they can play strong ecosystem roles.

ACKNOWLEDGEMENTS

We acknowledge funding support from the Lenfest Oceans Program.

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Figure 1. Map of Taputeranga Marine Reserve (black box, labelled Taputeranga MR), and area of the Wellington south coast area for which an EwE model was developed. The location of Taputeranga MR within New Zealand is shown as a red square in bottom right insert. The model area is characterised by different substrate types: intertidal reef (yellow); subtidal reef (red); and soft and mobile substrates (darker blue).
MODELLING THE MULTISPECIES FISHERY OF CHWAKA BAY, ZANZIBAR – BASIS FOR EXPLORATION OF USE AND CONSERVATION SCENARIOS

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ABSTRACT

The fishery of Zanzibar, a semi-autonomous Island state off the coast of Tanzania, is said to show serious signs of resource overexploitation and degradation of coastal habitats. Similar to many other East African regions, the fishery of Zanzibar is an artisanal, multispecies fishery with multiple gear use, lacking fundamental knowledge about stock size, age composition and spatial resolution of fishing effort and productivity. Comprehensive assessments of target resources are missing and therewith temporal and spatial moratoriums for exploited species. Marine reserves, so far, have been implemented based on biodiversity and habitat assessments, mainly focusing on the pristinity of habitats and the benefits for the tourism sector, thereby disregarding the fishery. The corresponding management actions therefore often lack the compliance of the respective fishing community.

The aim of the presented study is to assess the fishery of Zanzibar applying an ecosystem-based approach and to simulate use and management scenarios using the software package Ecopath with Ecosim and Ecospace.

Chwaka Bay, located at the east coast of Zanzibar was chosen as study site, since large spatial and temporal data sets are available for developing an ecosystem-based-model. Due to its environmental features the community strongly relies on fishing for income and protein supply (98%). The Bay comprises an area of 50 km² and consists of three coastal key habitats as nursery and breeding grounds of marine species: a fringing reef, protecting the inner bay, large seagrass meadows and the largest mangrove area on the island, located at the south of the bay. Chwaka Bay is part of the current MACEMP’s (Marine and Coastal Environment Management Project) Mnemba Island Marine Conservation Area management plan and a designated National Park since 2003.

The specific objectives of the study are three fold: 1) A description of the Chwaka Bay food web to elucidate the major flows and compartments of the system as well as characterizing the ecosystem in terms of productivity and transfer efficiencies. 2) Assessment of the state of the fishery on target resources and of resource productivity within the different habitats of the bay. 3) Simulation of spatial and temporal management scenarios to generate adequate zonation and management measures that allow for sustainable resource use, while maintaining fishermen income.

Figure 1. Figure of Chwaka Bay, modified from Muhando and Reuter 2014.
The biomass data for the different compartments of the food web model are based on catch information. The sampling period of the ongoing study lasts from January – June 2014 and September – December 2014. Biomass data are to be complemented with existing fish and invertebrate abundance studies conducted within the different habitats of Chwaka Bay. Production per biomass values for seven of the major target species are derived from catch curve estimates from fisheries data. Diet information is being obtained from stomach content analysis and existing feeding ecology studies of Chwaka Bay fish species. Fishing grounds and habitats are mapped to create the base map for spatial simulations. Historical catch and effort data, obtained from the Department of Marine Fisheries Resources on Zanzibar, are analyzed to evaluate temporal changes in fishing impacts on the ecosystem.

The study is the first attempt, to integrate data on target resource populations, fishing gears and economical parameters for a holistic evaluation of Zanzibar’s fisheries. Model outcomes will provide spatial and temporal management scenarios, which are expected to substantially contribute to the development of sustainable resource management strategies, as envisioned by MACEMP.

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The authors thank the Institute of Marine Science on Zanzibar (IMS) for the support in organizing and conducting the necessary fieldwork as well as the Department of Marine Fisheries on Zanzibar for providing valuable fisheries data.

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MODELLING SPATIAL EFFECTS OF ILLEGAL FISHING IN THE NORTH CASPIAN SEA ECOSYSTEM

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ABSTRACT

Nowadays, resource overexploitation and climate change are recognised as considerable threats to the sustainable development of socio-economic systems and environment. With growing evidence, highlighting the uncertain state and future of world fish stocks, new approaches to fisheries management that take account of fishing and climate change effects on ecosystems, are being called for. The Ecosystem Based Bio-resources Management, or EBBM is defined as a science based approach of managing human activities, such as fishing, fish stock enhancement, drivers of pollution/eutrophication with a view to, in parallel, conserve and sustainably use in the long-term run the nature living resources (Daskalov et al 2013). It is meant to deal with issues such as scientific assessment of the Caspian ecosystem and fisheries, environmental change, biological interactions, anthropogenic impacts, conservation and recovery of biodiversity, as well as the social and economic impacts. Major task to promote EBBM in the Caspian region was to also provide the decision-makers with innovative tools to support both traditional and innovative management practices. We apply an ecosystem model (EwE) to explore effects of IUUC (Illegal, Unreported and Unregulated Catches) on the ecosystem. The EwE model can provide testable insights into changes that have occurred in the ecosystem and help to design policies implementing EBBM in the Caspian.

The study proved that the ecosystem components and various fish populations in the Caspian interact in a rather complex way. The effects of predation and other multi-species interactions, combined with climate change and anthropogenic pressures create a formidable challenge for the ecosystem and bio-resource managers - a challenge that needs new approaches and directions. The proposed model demonstrates its ability to resolve multi-species interactions, habitats preferences and account for environmental and anthropogenic stressors, in the process of evaluating spatial management scenarios.

![Figure 1](image-url)  
**Figure 1.** Biomass change (%) in various fish groups in the original and extended (X) SPACE scenarios. Scenarios: SPACE describes effects of closing the original SPACE areas, SPACE IUUC describes effects of closing the SPACE areas and controlling IUUC inside of them, SPACE X describes effects of closing SPACE areas extended to 50% of the basin, and SPACE X IUUC describes effects of closing the extended SPACE areas and controlling IUUC. A Russian sturgeon B. Total fish biomass.

The most important factor dominating in all possible scenarios is the illegal fishing or IUUC. The main targets of the IUU fishing are the stocks of valuable fish resources, especially sturgeons. Therefore, the control over IUUC must be a priority target for the EBBM, especially when building recovery strategies for sturgeons (Figure 1).
The evaluation of spatial scenarios demonstrates that the effects of protected areas (Special Protected Areas for the Caspian ecosystem or SPACE) are proportional to the size of the closed areas, and specific (for different fish groups) to their placement. SPACEs have to be sufficiently large, and to cover the main target fish distribution areas. Effective IUUC control measures need to be enforced inside of the SPACEs, and even better in the whole region (Figure 2). The importance of the benthic pathways are pronounced in the North Caspian. It seems that pelagic and benthic systems are relatively decoupled. However, the relatively high importance of the benthic system may buffer the population explosion of the invasive Mnemiopsis leidyi, as a result the effect of this species in the North Caspian is expected to be less severe compared to other areas of the sea.

REFERENCES
DEEP-SEA ECOSYSTEM MODEL OF THE CONDOR SEAMOUNT

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ABSTRACT
Seamounts have been found to be areas of increased biodiversity, productivity and biomass. These ecosystems are also subject to intensive exploitation and therefore it is urgent to apply ecosystem based approaches towards the management of sustainable fisheries. Condor seamount (Azores, North east Atlantic) is a temporary protected area initially set for scientific research. The decision to close this seamount to fisheries arose from a collaborative, bottom-up process involving scientists, local fishermen, tourist operators and the Regional Government of the Azores. Despite the traditional importance of Condor for local demersal fishing fleet, the fishing associations supported the measure but asked for a continuous monitoring of the status of the ecosystem. Ecosystem models for the condor seamount were built to understand the interactions between fisheries, exploited species and the ecosystem that supports them, enabling impact assessments of human activities on the marine environment. Moreover, ecosystem models were used to have an alternative estimate of the time required for the recovery of selected fish stocks in that particular seamount. The Condor seamount model comprises 23 functional groups, including plankton, invertebrates, fishes, marine mammals and seabirds. The fisheries component consists on the regional fleet, with an emphasis on demersal fisheries. The model was fit to real data and simulations of the effect of fishing on Condor seamount conducted. Although fisherman expected the recovery of the seamount to happen in a 2-5 years our preliminary simulations suggested that the recovery of the seamount could take from 15-25 years. Although these results need further validation it highlights once again that a rapid recovery of a deep-sea ecosystem is unlikely.
IMPLEMENTING THE HABITATS DIRECTIVE IN GERMANY: CASE CONVENTIONS VERSUS ECOPATH, ECOSIM & ECOSPACE

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ABSTRACT
The Habitats Directive (92/43/EWG) is the most important law to protect listed species and habitats in the European Union. Since 2007, the Federal Agency for Nature Conservation (BfN) has recommended the application of 'Case Conventions' to implement the Habitats Directive in Germany (Lambrecht & Trautner 2007).

The Case Conventions defined spatial benchmarks for different habitat types and species that must be followed when a project might affect the protected area of a Natura 2000-site (Lambrecht & Trautner 2007). According to the European Court of Justice, there must be no doubts, if the case conventions declared that a project would not cause severe damage (EuGH, Rs. C-127/02, Slg. 2004, I-7405 – Cockle Fishery Rn. 43 f., 59).

However, the development of the Case Conventions raised doubts as ecological basic knowledge was ignored and the spatial benchmarks for listed species were developed in a discussion among experts (p. 80 in Lambrecht and Trautner (2007)) and were not derived from scientific experiments and statistical data analysis. Furthermore, this management tool completely ignores species interactions and indirect effects.

Today, only 28% of all habitat types are in a good condition and the majority of species in Germany is in a bad or deficient condition (Dröschmeister et al. 2014). One reason for this decline could be the application of Case Conventions, as this tool might be incapable of protecting listed species and habitats.

The Case Convention report provided an example to explain the application of spatial benchmarks (p. 63 – 66 in Lambrecht & Trautner (2007)). The study site showed a forest area (light green area, Fig. 1) that included two habitat sites (orange areas, Fig. 1) of the protected stag beetle (Lucanus cervus), a protected woodrush beech forest habitat (dark green area, Fig. 1) and arable farmland (brown area) that partly served as feeding habitat (light brown area, Fig. 1) for a protected bird, the red kite (Milvus milvus). The northern part of the study site was a protected Nature Reserve (yellow line, Fig. 1)

These habitats were impacted by a planned industrial area (black edging, Figure 1).

According to the Case Conventions, the environmental impact was negligible (Table 1). In order to assess the impact of the industrial area and the validity of the Case Conventions, an Ecopath model was developed that included the forest habitats, protected species and farmland (Figure. 1). In a second model, the industrial area was also considered and the modelled habitat areas were reduced in size according to the description in the report (p. 63-66 in Lambrecht and Trautner, 2007).
By comparing the Ecopath models before and after the construction of the industrial area, the results showed that the red kite would not be affected, but the stag beetle and the woodrush beech forest would decrease in biomass and also flow indices and system statistics were altered (Table 1). The Case Conventions were not able to detect these impacts.

<table>
<thead>
<tr>
<th>Listed species/ habitat (Habitats Directive 92/43/EWG)</th>
<th>Case Conventions</th>
<th>Ecopath</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stag beetle (<em>Lucanus cervus</em>)</td>
<td>-800 m²</td>
<td>9% biomass loss</td>
</tr>
<tr>
<td>Red kite (<em>Milvus milvus</em>)</td>
<td>-0.5 ha</td>
<td>No losses</td>
</tr>
<tr>
<td>Woodrush beech forest habitat (Code: 9110)</td>
<td>-1,700 m²</td>
<td>64% biomass loss</td>
</tr>
<tr>
<td></td>
<td>Changes in system statistics, flow and cycling indices</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Assessing the environmental impact of a planned industrial area on protected species and woodrush beech forest habitat in Figure 1 by comparing the results of the Case Conventions and Ecopath analysis

There is a need for a standardized method to implement the Habitats Directive in Germany (Lambrecht and Trautner, 2007). Ecopath, Ecosim and Ecospace are a much better tool than the Case Conventions in order to meet the legal requirements (Habitats Directive, Federal Nature Conservation Act (= BNatSchG)) for environmental management in Germany.

Ecopath is able to assess the status quo of an ecosystem (§9 BNatSchG) and is able to identify flows and functioning of the system, which have to be preserved (§1 (3), BNatSchG). Biological diversity and ecosystems have to be protected in the long-term and have to be used sustainably (§4 BNatSchG), which can be assessed by Ecosim. By applying Ecospace, the management scenario with the least environmental, spatial impact can be identified (§15 BNatSchG). Furthermore, this modelling technique can estimate the environmental impact of a project, investigate cumulative effects and help identify sustainable compensation measures (§15, 16, BNatSchG). For this reason, it is recommended to establish Ecopath, Ecosim and Ecospace as standard method for environmental management in Germany.

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EFFECTS OF MARINE PROTECTED AREAS AND FISHING ON POPULATION BIOMASS OF FIVE SPECIES OF SERRANIDAE IN LA PAZ BAY, MEXICO: AN ECOSPACE STUDY

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ABSTRACT

Many species of Serranidae are at risk of overexploitation in the northern Gulf of California due to their life-cycle and spawning behavior, which makes them susceptible to fisheries. The status of the species of this Serranidae family however, is unclear in the La Paz Bay but it is expected that they suffer from overfishing as the fisher act under an open access scheme and shrimp fisher press for access but are not allowed to operate yet. The five target species of this study are Myctero perca rosacea, Paralabrax auroguttatus, Epinephelus niphobles, Epinephelus acanthuristius and Paranthias colonus.

In the La Paz Bay, a Marine Protected Area (MPA) has been implemented in 2007, which protects biodiversity and spawning grounds. The aims of this thesis are to model the effects of MPAs (including 2 additional hypothetical MPAs), the effects of rising fishing effort and the effects of shrimp fishing on the population biomass of five species of Serranidae in the La Paz Bay. Another aim is to model the optimal fishing effort/fishing mortality to get the maximum sustainable yield to see the status of the five target populations. These effects were modelled by the spatial trophic ecosystem modelling software Ecospace. The following questions are to be answered in this study:

• What are the expected/simulated effects of the Espiritu Santo MPA and other hypothetical MPAs on the biomass development of the populations of the five target species?

• Which MPA scenario gives the highest relative catch for each of the five target species?

• What are the expected/simulated effects of rising fishing effort on the population biomass development of the five target species?

• What are the expected/simulated effects of shrimp fisheries on the population biomass development of the five target species?

To answer these questions, different scenarios were constructed, with different MPAs, including and excluding shrimp fisheries and with different fishing efforts. This model is based on three previous models by Arreguin-Sanchez et al. (2004), Díaz-Uribe et al. (2007) and Arreguin-Sanchez et al. (2007).

It was found that during present conditions, for one species (M. rosacea), the three MPAs combined lead to the highest increase in biomass, while for the other target species, the MPAs are less effective. However, the catch is highest when only two of the three MPAs are implemented.

The model also shows, that increasing fishing effort leads to extinction of all five target species, only M. rosacea can be protected by MPAs. The results suggest that the shrimp fisheries have mostly negative effects on the target species and increase the efficiency of the MPAs to protect the target species.
Figure 1. Total Difference in % of relative biomass comparing each MPA scenario with the MPA 0 scenario, pooling all target species per MPA scenario, with steady fishing effort and excluding shrimp fisheries.

The model also suggests, that shrimp fisheries lead to the overexploitation of 4 target species (excluding M. rosacea), while without shrimp fisheries all target species are shown as underexploited. This leads to the conclusion, that MPAs are not efficient for all Serranidae populations and need to be supported by fisheries management. Although the Serranidae populations are presently underexploited, a preventive fishing management would help to avoid overexploitation in the future.

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REFERENCES


INFORMING AND PLANNING MARINE CONSERVATION: POSTER PRESENTATIONS

NEW SOFTWARE PLUG-IN TO CALCULATE BIODIVERSITY AND CONSERVATION-BASED INDICATORS FROM EwE FOOD WEB MODELS

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ABSTRACT
Biodiversity decline and increase of species at risk is one of the most pressing world crises, and there is a growing global concern about the status of biological resources upon which human welfare depends (Butchart et al. 2010). Even if proven global extinctions remain scarce in the sea compared to terrestrial systems, local or even regional diversity declines have been observed in many marine ecosystems (Dulvy et al. 2014) under cumulative human impacts including overfishing, habitat degradation, and pollution.

Ecosystem food web models provide a variety of results that can be used to inform biodiversity and conservation issues since they can take into account the dynamic of commercial and non-commercial species, their interactions and the main drivers. These results provide insights about the status and dynamics of different level of biological organization, from species to ecosystem level, providing useful ecological indicators to be used for marine conservation planning. Such indicators are needed to fulfil the targets of different National and Transnational management plans and conventions, such as the European Marine Strategy Framework Directive (MSFD) or the Convention on Biological Diversity (CBD).

To enable the standardized calculation of several of the most widely used ecological indicators to inform biodiversity and conservation-based issues, we have developed a plug-in for the Ecopath with Ecosim software (Christensen and Walters 2004) that calculates these indicators from aquatic food web models.

Figure 1. Ecopath plug-in results applied to the Southern Catalan Sea model representing 1978 (Coll et al. 2006).

This plug-in is freely distributed with the EwE software and can be used to calculate indicators from the snapshot Ecopath model, the temporal-dynamic module Ecosim, and the temporal-spatial module Ecospace. Ecological indicators are divided in i) Trophic-based, ii) Biomass-based, iii) Catch-based, iv) Species-based, and v) Size-based indicators (Figure 1). The Biodiversity plug-in is connected to the Monte Carlo simulations routine in Ecosim, calculating the ecological indicators for each Monte Carlo simulation taking input range parameters into account (Figure 2). The plugin is also connected to Ecospace, calculating indicators over time and space (Figure 2).

The first step to use the plug-in is to define the taxonomic composition of functional groups in the new “Define Taxa” form in Ecopath. Once defined, users can enter detailed information per species or functional group related, for example, to the species ecology (e.g. type of organism, such as invertebrate or fish), species traits (e.g. mean max length) and species conservation status (e.g. IUCN status) in the new “Taxonomy” form under Ecopath Tools. This taxonomic information is then used by the plug-in to calculate the ecological indicators. The plug-in can be set to automatically save results, or can save results from its user interface.

Technical limitations of the plug-in include limited capability of EwE models to represent size-based changes in food webs, and lack of variation in the proportion of species in catch and biomass of each functional group if species are not parameterized as individual groups or multi-stanza groups. Data shortage in taxonomic resolution of some groups (e.g. invertebrates) can limit the applicability, too. The interpretation of results from the plug-in should take these limitations into account.
TOWARDS A BALANCE BETWEEN COMPLEXITY AND FEASIBILITY IN FOOD-WEB MODELS OF MEDITERRANEAN COASTAL ECOSYSTEM: ADDRESSING UNCERTAINTY WHILE ACCOUNTING FOR DATA COLLECTION CONSTRAINTS

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ABSTRACT

Mass-balance trophic models (Ecopath and Ecotroph) are valuable tools to describe ecosystem structure and functioning, to identify target species to be monitored and to allow comparisons of ecosystem states under different management options. Nevertheless, the use of the Ecopath modelling approach is generally constrained by two major sources of uncertainty, model complexity and quality of the input data. Both constraints strongly limit the construction of Ecopath models, especially for complex Mediterranean coastal ecosystems.

Here we developed an approach aiming at identifying an optimum and standardized model structure to represent coastal Mediterranean marine food-webs that accounts for trade-offs between feasibility, complexity and uncertainty. Starting from a highly detailed reference model of the Port-Cros National Park (NW Mediterranean Sea), we assessed which aggregation choices, driven by a simplification of sampling effort, should be avoided since they strongly affect the Ecopath and EcoTroph model outputs. Subsequently, we identified for which functional groups imprecise input biomass significantly alter model description of ecosystem functioning and trophodynamics. High trophic level predators, abundant primary producers (Posidonia oceanica) and groups with high biomass and/or diversified diet (epifauna, decapods, planktivorous fish and cephalopods) significantly affected the model structure, with different relative effects on the trophic structure and the maturity and complexity indices of the ecosystem. When building trophic models for similar ecosystems, priority should be given to the collection of local and accurate biomass data especially for the functional groups we identified. Our methodological approach for addressing model simplification could allow for increasing the feasibility of Ecopath applications in Mediterranean coastal zones, improving our knowledge of these ecosystems. In particular, fostering food-
web modelling on coastal marine protected areas would help to better inform management decisions and increase the efficiency of monitoring programs.

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USING MODELS TO ASSESS ECOSYSTEM INDICATORS AND DEFINE TARGETS OF THE GOOD ENVIRONMENTAL STATUS

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ABSTRACT
There is a worldwide emergent need for simple indicators to assess the environmental status of marine ecosystems. These indicators must reflect the effects of fluctuations in fishing pressure and be easily implemented in an Ecosystem approach to fisheries management (EAFM). Here, we tested various indicators computed from community size and trophic spectra, assuming that both types of spectrum correctly reflect the functional biodiversity of marine food webs. The indicators include the slope, the 95th percentile, the mean length, weight or trophic level, the equitability, the large fish indicator, the high trophic level indicator and the total abundance of the simulated spectra are compared between current spectra and potential reference situations. Four ecosystems were used as case studies: the Bay of Biscay/Celtic Sea, North Sea and English Channel ecosystems. Current size spectra are obtained from scientific surveys data and trophic spectra from pre-existing Ecopath models, while reference situations are estimated by simulations. Reference situations are simulated at three different fishing pressures: the virgin state and two candidate targets for an EAFM, one with fishing mortality=0.2 and the other with fishing mortality=natural mortality for all exploited species. Simulations are developed using 3 different methods: (i) demographic simulations at equilibrium for size spectra; (ii) EcoTroph simulations for trophic spectra; (iii) Ecosim simulations for trophic spectra. Inter-ecosystems comparisons are done to contrast the reference situations, analysis the responses of all indicators, and assess the states of the studied ecosystems. Sensitivity analyses are also conducted on the main simulation parameters to test the robustness of the chosen indicators. Preliminary results underline the sensitivity of the target values to the choice of the species composing the size spectra, while some trophic indicators appeared sensitive to the value of certain ecological parameters such as the top-Down effect used in EcoTroph. We also identify a subset of operational indicators to assess the good status of marine food webs, and suggest reference values for an effective EAFM. Current states indicator values exhibited improving trends, especially in the Bay of Biscay and Celtic Sea, but remained below target values in the three other ecosystems. We conclude that our selection of indicators is especially relevant to assess multiannual trends in marine ecosystems.

ANALYZING THE COLLAPSE AND LACK OF RECOVERY OF TWO NOTOTOHENIID STOCKS IN THE ANTARCTIC PENINSULA (SUB AREA 48.1)³²

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ABSTRACT

The Antarctic Ocean region has experienced noticeable changes in last decades, among which we can mention the collapse of several fisheries due to overfishing (Kock, 1992; Constable et al., 2000). Fishing exploitation in the Antarctic continent started in late 1960s with Notothenia rossii and Gobionotothen gibberifrons as main target species (Kock, 1992). The most of the catches were registered in the first two years of the fishery, seriously reducing both stocks (Kock, 1992; Kock, 1998; Barrera-Oro et al., 2000). In 1985 the fishery based on N. rossii was closed and in 1990 an indefinite ban was established for fish in the Antarctic region. However, recent assessments indicate that the biomass of N. rossii and G. gibberifrons in the region has continued to decline and that recovery is lacking even in the absence of fishing (Jones et al., 2000; Barrera-Oro et al., 2003; Marschoff et al., 2012). The lack of recovery in these two stocks after 30 years and the understanding of the impact of their collapse in the ecosystem have not been addressed. Therefore, the objective of this study is to evaluate the possible causes of the collapse and lack of recovery of N. rossii and G. gibberifrons in the marine ecosystem off the Antarctic Peninsula.

Using the EwE software (EwE) (Christensen y Walters, 2004) we built a model that represents the food web in the sub-area FAO 48.1 (figure 1) at the Antarctic Peninsula (60° S a 65° S; 50° W a 70°W), covering a surface area of 672000 km². The model considers the system conditions in year 1977, previous to the exploitation of N. rossii and G. gibberifrons in the zone, and the simulation period covers from 1979, onset of the fishery in the Peninsula, to year 2010. Our model considers 23 functional groups that include all trophic levels, from primary producers to top predators. However, the model is focused on the trophic interactions of the two target stocks N. rossii and G. gibberifrons.

Input parameters (biomass, production/biomass, Consumption/biomass, diets and landings) were either gathered or calculated from available information. Once the model was found to be properly balanced, we simulated changes in fishing mortality in N. rossii and G. gibberifrons during the exploitation period and anomalies in models primary production forced by changes in atmosphere and ocean circulation at large

scale. We did not simulate changes in predation as forcing since there is no evidence that predators of N. rossii and G. gibberifrons (birds and whales) have increased in last decades.

Simulation results (figure 2) show that fishing mortality does not cause the collapse of the biomass of N. rossii and G. gibberifrons, unless reported landings had been seriously underreported during the first years of the fishery (figure 2a). On the other hand, changes in the primary production explain the decline in the biomass, but not the lack of recovery in N. rossii and G. gibberifrons in the long-term (figure 2b). We conclude that the collapse and lack of recovery of N. rossii and G. gibberifrons is better explained by a combined effect of intense fishing and a likely long-term system decline primary production (figure 2c).

ACKNOWLEDGEMENTS

We are grateful to Programa COPAS Sur Austral, INCAR Centre and FONDECyT Project 11110545

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TROPHIC MODELS IN THE SOUTHWESTERN ATLANTIC OCEAN: EVALUATING STRUCTURE AND FUNCTIONING OF COASTAL ECOSYSTEM

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ABSTRACT

Knowledge about the structure and functioning of marine ecosystems is of outmost importance to the management perspective and to the development of ecosystem science theory. Formal models play a fundamental role to improve our understanding and allow us to represent the trophic interactions between multiple species including fisheries within an ecosystem. In the last years, the Ecopath with Ecosim (EwE) approach is the most used and tested ecosystem modelling tool for addressing ecosystem-level responses both to changes in fishing and the influences of the environmental forcing. Coastal marine food webs are subjected to anthropogenic and environmental disturbances that can impact ecosystem structure and functioning, and thus affect natural resource availability.

Particularly, at coastal zones of the Southwestern Atlantic (SWA, 25° S - 41° S) the oceanographic dynamics is complex, their ecosystems are highly productive and diverse, representing high socio-economic relevance within the region. Despite this, the structure and functioning of the diverse coastal ecosystems occurring in the SWA is just beginning to been analyzed in the scientific literature. Here, we reviewed and discussed most ecotrophic models developed in different coastal zones of SWA: 1 - South Brazilian shelf; 2- Rio de la Plata estuary; 3- Reflective sandy beach; 4- Dissipative sandy beach; 5- Rocha coastal lagoon; 6- North of Argentina shelf 1983 and 7- North of Argentina 2005. Common features and model limitations are discussed.

The models indicated that SWA ecosystems are highly productive and diverse, with relatively high trophic levels, and catches which impact their stability, structure and maturity. Strong differences in the ecosystem structure are showed by the species composition and the formation of functional groups. Sandy beach ecosystems and the coastal lagoon showed a reduced number of species contrasting with the estuarine and shelf ecosystems. In the simpler systems (e.g. sandy beaches) trophic aggregation was practically unnecessary and most groups were represented as single species.

Most models (excepting beaches) basically showed the same fisheries target species, where the Sciaenidae (Micropogonias furnieri, Cynoscion guatucupa and Macrodon ancyodon) display strong dominance in the catches.

Regarding ecosystem growth and development (maturity) both the lagoon and coastal shelf models appear as mature, while sandy beaches are presented by an immature state. Ecosystem attributes based on primary production (e.g. PP/B) result strongly influenced by the high PP found in all the ecosystems considered.

Table 1. Ecosystem and fisheries attributes represented by the trophic models of the SWA: 1 - South Brazilian shelf; 2- Rio de la Plata estuary; 3- Reflective sandy beach; 4- Dissipative sandy beach; 5- Rocha coastal lagoon; 6- North of Argentina shelf 1983 and 7- North of Argentina 2005.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Units</th>
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<tr>
<td>Total area</td>
<td>119000</td>
<td>70500</td>
<td>3,5</td>
<td>1,1</td>
<td>72,0</td>
<td>109000</td>
<td>109000</td>
<td>km²</td>
</tr>
<tr>
<td># groups</td>
<td>35</td>
<td>37</td>
<td>20</td>
<td>9</td>
<td>27</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Max trophic level</td>
<td>4,6</td>
<td>3,96</td>
<td>3,14</td>
<td>3,05</td>
<td>4,2</td>
<td>4,31</td>
<td>4,72</td>
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</tr>
<tr>
<td>Sum of all consumption</td>
<td>2341,8</td>
<td>3675,0</td>
<td>1514,0</td>
<td>1514,0</td>
<td>806,2</td>
<td>12197,1</td>
<td>6294,2</td>
<td>t/km²/year</td>
</tr>
<tr>
<td>Sum of all exports</td>
<td>822,1</td>
<td>19521,0</td>
<td>19212,0</td>
<td>8041,0</td>
<td>34,6</td>
<td>408,9</td>
<td>380,8</td>
<td>t/km²/year</td>
</tr>
<tr>
<td>Sum of all respiratory flows</td>
<td>1200,1</td>
<td>1989,0</td>
<td>828,0</td>
<td>541,0</td>
<td>130,5</td>
<td>6756,9</td>
<td>3343,5</td>
<td>t/km²/year</td>
</tr>
<tr>
<td>Total system throughput (TST)</td>
<td>5436</td>
<td>45683</td>
<td>41208</td>
<td>18052</td>
<td>451</td>
<td>21851</td>
<td>11338</td>
<td>t/km²/year</td>
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<tr>
<td>Sum of all production</td>
<td>2680</td>
<td>21760</td>
<td>20424</td>
<td>8925</td>
<td>389,0</td>
<td>10701</td>
<td>5696</td>
<td>t/km²/year</td>
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<tr>
<td>Mean trophic level of the catch</td>
<td>3,37</td>
<td>2,95</td>
<td>--</td>
<td>3,15</td>
<td>3,71</td>
<td>3,49</td>
<td></td>
<td></td>
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<tr>
<td>Gross efficiency (catch/PP)</td>
<td>0,000234</td>
<td>0,000051</td>
<td>--</td>
<td>0,001541</td>
<td>0,000193</td>
<td>0,000473</td>
<td></td>
<td></td>
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<tr>
<td>Total primary production/total respiration (PP/R)</td>
<td>1,669</td>
<td>10,5</td>
<td>20,6</td>
<td>15,9</td>
<td>2,290</td>
<td>1,048</td>
<td>1,11</td>
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<tr>
<td>Total primary production/total biomass (PP/B)</td>
<td>28,09</td>
<td>81,14</td>
<td>220,6</td>
<td>184,4</td>
<td>8,701</td>
<td>23,62</td>
<td>22,972</td>
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<tr>
<td>Total biomass/total throughput (B/TST)</td>
<td>0,0131</td>
<td>0,005</td>
<td>0,002</td>
<td>0,003</td>
<td>0,076</td>
<td>0,014</td>
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<tr>
<td>Total catches</td>
<td>0,4688</td>
<td>1,1</td>
<td>--</td>
<td>0,461</td>
<td>1,369</td>
<td>1,755</td>
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<td></td>
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<td>Ascendency</td>
<td>43,4</td>
<td>53,4</td>
<td>68</td>
<td>59</td>
<td>27,4</td>
<td>41,5</td>
<td>54,3</td>
<td>%</td>
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<tr>
<td>Overhead</td>
<td>56,6</td>
<td>46,6</td>
<td>32</td>
<td>41</td>
<td>72,6</td>
<td>58,4</td>
<td>45,7</td>
<td>%</td>
</tr>
<tr>
<td>Primary production required (PPR)</td>
<td>27,7</td>
<td>3</td>
<td>--</td>
<td>28,7</td>
<td>3,99</td>
<td>14,39</td>
<td>%</td>
<td></td>
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<tr>
<td>Pedigree</td>
<td>0,386</td>
<td>0,526</td>
<td>0,51</td>
<td>0,52</td>
<td>0,681</td>
<td>0,636</td>
<td>0,687</td>
<td></td>
</tr>
<tr>
<td>Mean Transfer efficiencies</td>
<td>11,8</td>
<td>9,4</td>
<td>2,3</td>
<td>1,2</td>
<td>16</td>
<td>23,6</td>
<td>26,1</td>
<td>%</td>
</tr>
</tbody>
</table>

The lack of information about, production and consumption rates and food preferences of many biological components, are common constraints between models. Currently most of ecotrophic models are static, however, with the development of spatial-temporal dynamic models, will be possible to predict future scenarios about the potential ecosystem changes due to fishing effort (e.g. distribution and size of fishing fleets) or due to variability on climatic regimes (e.g. El Niño / La Niña, global warming) or by the use of marine space (e.g. oil exploration, marine protected areas).

ACKNOWLEDGEMENTS
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ECOSYSTEM EVOLUTION AND CHALLENGES FOR MANAGEMENT: ORAL PRESENTATIONS

CONFLICTING OBJECTIVES FOR ECOSYSTEM BASED FISHERIES MANAGEMENT

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ABSTRACT

Current fisheries management is oriented towards management of single fish stocks, considered largely as independent, isolated units. However, management actions directed towards one stock, or one fishery, has implications for other parts of the ecosystem. Accounting for such indirect effects in an ecosystem approach to fisheries management requires food-web models that can quantify how perturbations on one part of the ecosystem influences the entire ecosystem. I will show how food-web models can be used to as tools to guide strategic fisheries management decisions through examples of trophic cascades and rebuilding strategies. In particular I will show how, due to the intrinsic dynamics of a ecosystems, a management action may lead to an unfavourable outcome in the short time, while a favourable outcome will only happen after a certain time has elapsed. Finally I will discuss fundamental challenges and obstacles that models need to overcome to provide a successful operational implementation of ecosystem-based advice.

Model. The simulations are based on a trait-based size-spectrum model (Andersen and Beyer 2006; Andersen and Pedersen 2010). The model represents a generic fish community with rates calibrated to resemble the North Sea. The model does not resolve individual species but represents the fish community as a distribution of individuals as a function of size (weight, $w$) and asymptotic size ($W_{inf}$). The central assumption in the model is that big individuals eat smaller individuals. This leads to food-dependent growth and reproduction of the predators and to a corresponding mortality on prey. Consumption follows a functional response type II. The stabilizing mechanism in the model is that reproduction is density-dependent following a Beverton-Holt type of stock-recruitment relationship. The driving force in the model is the fishing mortality which is specified as a function of individual size and asymptotic size. The type of fishing mortality used here is a “trawl-type” selectivity where fishing starts at $0.05$ times the asymptotic size and quickly achieves the maximum fishing mortality.

Basic simulation. As a base case consider a fish community where all species are exploited, such as the North Sea. All species are fished with the trawl selectivity and a fishing mortality of $0.5$ year$^{-1}$. This corresponds to a fully exploited system. The resulting biomass distribution is shown in Figure 1.

Ecosystem recovery example. As an example consider a complete reduction of the fishing mortality on all species with an asymptotic size larger than $8$ kg. This leads to increase in biomass of those species. This recovery triggers a trophic cascade which propagates down through all the trophic level (Figure 1). Those species just smaller than the recovered species decrease in biomass, those smaller increase, and the very small species again decrease (Figure 2a). The recovery takes some time. The fastest response is on the largest species that first have a strong recovery. This is followed by a reduction towards the steady state (Figure 2b). The initial strong recovery results in a large depletion of the medium-sized species, etc. The simulation illustrates three important points: 1) The recovery of the entire community takes longer time

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than the recovery of the directly affected species; 2) the initial response may be quite different from the final response; 3) the steady state is reached after around 20 years.

**Figure 1.** The biomass distribution of all individuals irrespective of species as a function of weight. Black line: fully exploited system; grey line system with no fishing on large species.

**Figure 2.** a: The change in the biomass distribution following the reduction of fishing on large species. This shows the spawning-stock biomass as a function of asymptotic size (thick line) relative to the fully exploited situation (dashed line). b: The change in the biomass of large species (thick line), medium species and small species (thin line) as a function of time.

**REFERENCES**


BEYOND ANECDOTAL INFORMATION: THE USE OF FISHERS’ KNOWLEDGE TO MODEL FISHERIES

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ABSTRACT

Ecosystem modeling to inform fisheries management is still hampered by the lack of scientific information, mainly in developing countries and remote areas. In Brazil, small-scale fisheries have always been poorly sampled but in the last 5 years the political inability of institutions in charge of fisheries monitoring has undermined the registration of fish landings and, consequently, the acquisition of information on fishers, fish stocks, fishing fleet and catches. The situation is slightly worse in the Brazilian northeastern coast, where despite its importance, artisanal fisheries are historically poorly studied. In this region, there is not enough data available to perform fisheries modeling and design management plans, with the exception from Freire and co-workers (2008). Given that fishers’ knowledge has been used to complement scientific data and to provide information on biology and ecology of exploited fish stocks in other areas, here we recorded such knowledge with the principal aim to contribute data to elaborate an ecosystem model using Ecopath representing the marine exploited ecosystem of Formosa Bay, in Natal State, Brazil.

After one year recording landings (from Feb/13 to Feb/14), we identified the 10 most caught fish species and the most skilled fishers in catching those species, who were then interviewed. Fishers were selected by the gear used (11 used gillnets and 12 used hook and line), by fishing experience (>10yrs) and by age (>25yrs). The age of the interviewed fishers ranged from 25 to 57 yrs. These interviewees have been fishing from 13 to 45 yrs and together they represented 338 yrs of fishing experience. Each expert answered question about the main fish targeted, in average 4 to 5 fish species per fisher. Face-to-face interviews were conducted between February and April 2014. Data collection followed the Delphi methodology (MacMillan & Marshall, 2006), in which experts are consulted and results are submitted to their approval or revision until at least 51% of experts have reached consensus and agreed on the results. Accordingly, each fisher was provided with photos of their main species caught. Once a fisher had answered about the first species chosen, other species were presented and fishers could decide on answering or not about species depending on their knowledge. Pictures of food items were also presented to fishers to assist them when informing about diet items. A known quantity of corn seeds was used to represent the amount of each species caught by fishers, and they were encouraged to add as many corn seeds as they wanted to coarsely represent the total size of each fish stock.

The information requested during interviews was the maximum weight ($W_{\text{max}}$), modal weight ($W_{\text{modal}}$), maximum length ($L_{\text{max}}$), modal length ($L_{\text{modal}}$), growth rate, longevity, diet, amount of food required per day and main predators for the ten most caught species. Fishers could use a piece of string to show their perception on $L_{\text{max}}$ and $L_{\text{modal}}$ in cm. In some cases, fishers provided this information in kg and weight-length relationships were used to estimate the length ($L$). The $L_{\text{max}}$ provided by fishers was used to estimate $L_{\infty}$ using the empiric equation from Froese and Binohlan (2000). A $t$-test was used to compare $Q/B$ estimated using fisher’s $W_{\infty}$ with $Q/B$ available in Fishbase.

Afterwards, results from all answers and a trophic web elaborated using the Ecopath software taking into account fisher’s information was presented individually to each fisher and they could change or keep the information previously provided. An Ecopath model was then elaborated using the ten most caught species, their prey and predators, and using information found in Fishbase (fishbase.org) and SeaLifeBase (sealifebase.org), in addition to what was collected with the fishers’ interviews. Less than ¼ of fishers (22.7%) provided information about the size of the largest fish caught in cm, but all were able to provide the weight of the largest fish caught. Fishers were not able to provide information on life expectancy, total amount of fish of each species caught per year and stock size. Additionally, growth rates provided by fishers just about four fish species ($\text{Thunnus atlanticus}$, $\text{Scomberomorus brasiliensis}$, $\text{Euthynnus alletteratus}$, $\text{Scomberomorus cavala}$).

Results showed that there was no statistical difference between $L_{\infty}$ provided by the fishers and $L_{\infty}$ estimated using the empirical equation for eight species. On the contrary, fishers underestimated $L_{\infty}$ for $\text{S. brasiliensis}$ and overestimated the one for $\text{Seriola fasciata}$ (Table 1), suggesting stock depletion for these species or selection by net sizes and fishing habitat.

<table>
<thead>
<tr>
<th>Species</th>
<th>$L_{\infty}$ <em>Fishbase</em></th>
<th>$L_{\infty}$ <em>Fishers</em></th>
<th>N Fisher</th>
<th>$t$ test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Scomberomorus brasiliensis}$</td>
<td>131.25</td>
<td>95.38</td>
<td>6</td>
<td>18.14</td>
<td>0.000</td>
</tr>
<tr>
<td>$\text{Seriola fasciata}$</td>
<td>70.87</td>
<td>159.89</td>
<td>3</td>
<td>10.32</td>
<td>0.009</td>
</tr>
</tbody>
</table>

**Table 1.** Length at infinity estimated by Froese and Binohlan (2000) using Fishbase data and according to data provided by fishers for species with significant differences.

With the exception of $\text{Mycteroperca bonaci}$ and $\text{Scomberomorus cavala}$, fishers usually underestimated $Q/B$ in relation to values found in the literature (Table 2).

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>$Q/B$ <em>Fishbase</em></th>
<th>$Q/B$ <em>Fishers</em></th>
<th>t-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Thunnus atlanticus}$</td>
<td>Blackfin tuna</td>
<td>7.22</td>
<td>9.5</td>
<td>26.42</td>
<td>0.000</td>
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<td>$\text{Mycteroperca bonaci}$</td>
<td>Black grouper</td>
<td>3.96</td>
<td>4.12</td>
<td>0.58</td>
<td>0.617</td>
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<td>$\text{Scomberomorus brasiliensis}$</td>
<td>Spanish mackrel</td>
<td>7.38</td>
<td>9.22</td>
<td>8.76</td>
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<td>$\text{Lutjanus analis}$</td>
<td>Mutton snapper</td>
<td>4.51</td>
<td>6.32</td>
<td>12.7</td>
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<td>3.20</td>
<td>6.46</td>
<td>29.70</td>
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<td>$\text{Seriola fasciata}$</td>
<td>Lesser amber jack</td>
<td>8.39</td>
<td>5.54</td>
<td>NC</td>
<td>NC</td>
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<tr>
<td>$\text{Coryphaena hippurus}$</td>
<td>Dolphinfish</td>
<td>4.01</td>
<td>5.34</td>
<td>10.38</td>
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<td>12.67</td>
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</tr>
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</table>

**Table 2.** Comparison between Consumption per Biomass ($Q/B$) estimated using Palomares & Pauly (1998) equation with scientific data and $Q/B$ estimated using $W_{\text{max}}$ provided by fishers. Fish species are ordered according to the abundance in landings.

Main predators quoted by fishers were sharks, dolphins and large pelagic fishes (such as $\text{Istiophorus albicans}$ I. albicans; $\text{Xiphias gladius}$; $\text{Makaira nigricans}$; $\text{Scomberomorus cavala}$; $\text{Sphyraena barracuda}$; $\text{Rachycentron canadum}$ and $\text{Seriola fasciata}$). Sharks were considered to feed on all other species, while dolphins, according to fishers, mainly feed on species caught by gillnets, likely indicating competition among fishers and dolphins while fishing. Overall, fishers information regarding feeding habits for all species was similar to the one provided in the literature, and fishers were able to supply details on the diet for six predators, broadening their diet composition in 1 to >3 items in comparison with data previously available.
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THE IMPORTANCE OF LOCALLY SPECIFIC DATA IN ECOPATH MODELS

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ABSTRACT
Ecopath food-web models have been use worldwide to examine and investigate food webs in different aquatic ecosystems. The information obtained from these models is very valuable, especially in the application of an ecosystem approach to fisheries management. However, data on appropriate spatial and temporal scales are often not available and data from elsewhere are inputted into the model, likely reducing accuracy of the model. Here we present a modified version of the Lees and Mackinson (2007) Irish Sea model using up-to-date information, in particular for top predators. Results of this model show an increase in food-web complexity with an increase of trophic levels and a decrease in the net system production, suggesting that a trend to maturation might be occurring when comparing with the previous model. Also, the model showed that the fishery was targeting at higher trophic levels that the previous model indicating which might be related to a new fishing scenario.
A DYNAMIC VERSION OF EcoTroph TO ASSESS CHANGES IN MARINE ECOSYSTEMS - APPLICATION TO THE BAY OF BISCAY AND CELTIC SEA CASE STUDY

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ABSTRACT

EcoTroph is a steady-state ecosystem model where the functioning of aquatic ecosystems is considered as a flow of biomass surging up the food web from lower to higher trophic levels, through predation and ontogenic processes (Gascuel and Pauly 2009, Gascuel et al. 2011). The model deals with trophic spectra of biomass, production, catch, fishing mortalities, i.e. the continuous distribution of a parameter at the ecosystem scale and as a function of continuous trophic levels. Trophic spectra related to a particular ecosystem and associated fisheries, are commonly derived from a pre-existing steady-state Ecopath model. EcoTroph enables the simulation of various fisheries changes and their impacts on computed trophic spectra. Thus, it constitutes a powerful tool to analyze fishing impacts at the ecosystem scale.

In this study, we developed a dynamic version of EcoTroph, ET-Dynamic (what is equivalent to the Ecosim dynamic extension of the steady-state Ecopath model). Such a dynamic tool allows both past-analyses and forecasts. It provides more confidence in the ecosystem modelling approach, allowing to better estimate some of the main parameters of the model, especially the strength of top-down controls. The model uses trophic spectra related to an initial state of the studied ecosystem as inputs, as well as time series of yearly primary productions and fishing patterns. Therefore, it can be used to simulate year to year changes in the ecosystem, and to identify drivers of these changes. Here, the model is tested analyzing the dynamic of the Celtic Sea and Bay of Biscay ecosystem, over the 1980-2012 period.

First, an Ecopath model was built to represent the Celtic sea and Bay of Biscay area (330 000 km²) in 1980. It includes 38 trophic groups, with a detailed representation at the species level for all stocks targeted by fisheries and assessed by ICES working groups. Then, based on estimates from ICES assessments, and using recruitment and fishing mortalities as forcing functions, an Ecosim model was fitted to time series of catch and biomass (Figure 1). Like many European seas, this ecosystem is characterized by very high fishing mortalities applied on demersal stocks during the 1990s. The fishing
pressure decreased over the last decade, but the total biomass of assessed stocks continues to decline. Total catches were especially high during the 1990s, mainly due to large landings of horse mackerel. Biomass trophic spectra computed for years 1980 and 2012, highlighted changes which have occurred during the very last years in the species composition, with an increase in high trophic levels, and a decrease for low trophic levels.

Figure 1. Trends in the Celtic sea and Bay of Biscay ecosystem. Top-left: mean fishing mortality of assessed stocks; Top-right: biomass observed (diamonds) and simulated (line) using Ecosim, for all assessed stocks; Bottom-left: total catch observed (diamonds) and simulated (line) using Ecosim; Bottom-right: Biomass trophic spectra in 1980 and 2012.

The dynamic EcoTroph model, developed under the R environment, was also used to simulate the 1980-2012 period, using yearly catch trophic spectra as input. The model provides yearly biomass and fishing mortalities trophic spectra, which can be compared either to estimates derived from ICES assessments or to Ecosim results. Sensitivity analyses show that the trophic flow kinetics and the strength of the top down control (α parameter) have significant effects on simulations. Using appropriate parameters, the model is able to simulate changes observed in the biomass of high trophic levels, while for low trophic levels we have to assume that the flow kinetics and the transfer efficiencies have changed over time. The first one can be affected by environmental conditions, while the latter one would be impacted by fisheries-induced changes in the global functioning of the ecosystem.

We concluded that the dynamic EcoTroph model provides new insight into the functioning of marine ecosystems and a useful tool to analyze dynamics and drivers of change. The next step will be to run forecast simulations according to various fishing scenarios and using results of the past-analysis to better estimate the model parameters.

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SIMULATION OF ZEBRA MUSSEL INVASION AND EVALUATION OF IMPACTS ON THE MILLE LACS LAKE, MINNESOTA: AN ECOSYSTEM MODEL

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ABSTRACT

In less than a decade after being first noticed in 2005, Zebra mussels *Dreissena polymorpha* became fully-established in Mille Lacs Lake, Minnesota, USA. To explore the ecosystem-wide impact of this potentially damaging species in the premier walleye *Sander vitreus* lake, an ecosystem model with 51 functional groups was built using Ecopath and Ecosim modeling suite. The model was tuned to observed time series of fish abundance and fisheries catch data from 1985 to 2006. We setup zebra mussel with a high initial biomass, and an adequate fishing pressure was applied on it with an aim to neutralize the effect on ecosystem caused by the inclusion of zebra mussel. At the onset of 2005, the fishing pressure was released with different trajectories so that we could mimic the non-nutritional challenges the species could have faced during its irruption in the lake. The fitted model were simulated to the year 2036; the simulation results indicated system-wide collapse of major predators including walleye due to the effect of bottom-up cascading as zebra mussel efficiently filters out the phytoplankton from the system. The result also indicated that the population of zebra mussel in the lake stabilized after attaining the maximum density within few years. Furthermore, the model predicted a significant boost in smallmouth bass *Micropterus dolomieui* population when zebra mussel was incorporated in the diet of the crayfish; remarkably, the predatory pressure did not cause a large impact on zebra mussel biomass. Our capability to predict the response of the Mille Lacs Lake to zebra mussel invasion would largely depend on the dynamics of plankton groups, the response of juveniles of higher trophic fish species like walleye to the changing dynamics of plankton groups, and the response of yellow perch *Perca flavescens* population.
WHALING, PRIMARY PRODUCTIVITY AND THE CHANGING STRUCTURE OF THE
SOUTHERN OCEAN FOOD WEB

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ABSTRACT

The aim of this study was to examine the ecological plausibility of the “krill surplus” hypothesis (Laws 1977) and the effects of whaling on the Southern Ocean food web (Ainley et al. 2009, Ballance et al. 2006) using mass-balance ecosystem modelling. Laws (1977) argued that the depletion of rorqual populations in the Southern Ocean led to an increase in the biomass of Antarctic krill, which in turn facilitated an increase in the abundances of several species of penguins and pinnipeds. In this study, the depletion trajectory and unexploited biomass of each rorqual population in the Antarctic was reconstructed using yearly catch records and a set of species-specific surplus production models (Baker and Clapham 2004). The resulting estimates of the unexploited biomass of Antarctic rorquals were used to construct an Ecopath model of the Southern Ocean food web existing in 1900. The rorqual depletion trajectory was then used in an Ecosim scenario to drive rorqual biomasses and examine the “krill surplus” phenomenon and whaling effects on the food web in the years 1900-2008. An additional suite of Ecosim scenarios reflecting several hypothetical trends in Southern Ocean primary productivity (Arrigo et al. 1998, Boyce et al. 2014) were employed to examine the effect of bottom-up forcing on the documented krill biomass trend (Atkinson et al. 2004). The output of the Ecosim scenarios indicated that while the “krill surplus” hypothesis is a plausible explanation of the biomass trends observed in some penguin and pinniped species in the mid-20th century, the excess krill biomass was most likely eliminated by a rapid decline in primary productivity in the years 1975-1995 (Trathan et al. 2012, Trivelpiece et al. 2011). Our findings suggest that changes in physical conditions in the Southern Ocean during this time period could have eliminated the ecological effects of rorqual depletion, although the mechanism responsible is currently unknown. Furthermore, a decline in iron bioavailability due to rorqual depletion (Nicol et al. 2010) may have contributed to the rapid decline in overall Southern Ocean productivity during the last quarter of the 20th century. The results of this study underscore the need for further research on historical changes in the roles of top-down and bottom-up forcing in structuring the Southern Ocean food web. They also demonstrate the utility of ecosystem modelling in general, and Ecopath with Ecosim in particular, in reconstructions and examinations of the past and current states of pelagic ecosystems and the complex processes that link them, as well as the importance of such considerations for ecosystem-based fisheries management.
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REGIME SHIFTS IN THE NORTHERN BENGAUELA, CHALLENGES FOR MANAGEMENT

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ABSTRACT
Managing marine ecosystems are made difficult by lack of information, our inability to sample at all trophic levels, and our lack of understanding of the structure of the ecosystem and how it changes due to pressures put on the system. Thus it is very difficult to understand where the “pinch points” are and how to manage systems that have flipped into new regimes. In some well-studied systems such as the North Sea (Kenny et al. 2009, Mackinson et al. 2009) and the Baltic Sea (Tomczak et al. 2013) these problems have been overcome to some extent and the changes in the ecosystem structure are relatively well understood. However in a system which has been significantly less well studied, such as the Northern Benguela ecosystem, our understanding of how the ecosystem has changed, and why it behaves different from the adjacent Southern Benguela ecosystem is much less well understood.

Over the past 50 years, overexploitation and environmental variation has caused the Northern Benguela to be much less productive in terms of fish yield (Hampton and Willemse 2012). During that time the main planktivorous fish in the system changed from sardines, Sardinops oscellatus, to horse mackerel, Trachurus capensis, and bearded gobies, Suffoglobius bibarbatus (Cury and Shannon 2004). The system has been subjected to similar environmental variation as the southern Benguela, but the fish stocks were not as well managed prior to Namibian Independence from South Africa in 1990 and therefore the stocks are now not as robust as similar species in the south (Cury and Shannon 2004). It seems to have changed from an efficient ecosystem dominated by sardine and anchovy, to the largely resilient system in the 1980s dominated by horse mackerel, mesopelagics and other small pelagics, and a less resilient system in the 1990s, where only horse mackerel dominated (Heymans et al. 2004).

In this paper we will use the existing ecosystem model of the Northern Benguela (Heymans et al. 2009) fitted over the past 50 years to time series, to describe the different pressures on the ecosystem, to address the impact that these pressures have had on the structure of the ecosystem and to describe the consequential regime shifts in the ecosystem using ecological network analysis indices. We also undertook an Integrated Trend Assessment including a STARS analysis, PCA and chronological cluster analysis of the input data and model outputs to describe the changes over time. This description of the changes in the structure of the ecosystem will help us address the issues of how to manage a changed ecosystem into the future.

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Figure 1. This figure illustrates the changes in pelagic structure in the Northern Benguela over the past 50 years. Blue line is Sea surface temperature, red line is the PC2, which is driven mainly by sardine catch and purse seine effort, with shifts in these drivers in the early 1970s and the mid-1980s.

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NICHE CONSTRUCTION THEORY AND ECOSYSTEM STANZA MODELLING: NORTHERN BC FISHERIES

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ABSTRACT
According to niche construction theory, all organisms, including humans, both adapt to and modify their local selective environments, thereby influencing their own evolution and that of other organisms (Lewontin 2003, Laland et al. 2000, 2004, Odling-Smee et al. 2003). The evolutionary legacy of active human niche construction (Kendal et al. 2011) introduces additional inheritance systems into evolution (Jablonka and Lamb 2005), mediated by the environment (Bonduriansky 2012). Humans actively construct their environment and their evolution through, for example, landscape and species distribution changes, changing social practices and belief systems, and complex patterns of cultural change (Jablonka 2011). We apply niche construction theory to examine the interaction between coastal ecosystems and their adjacent human communities over archaeological and historical time scales. We have developed an innovative ecosystem stanza approach to modelling stable ecosystem states, defined as stanzas or niches, to compare ecological niches against periods of cultural stability or cultural niches. This novel evolutionary ecological approach will be used to compare the sustainability and implications on ecosystem structure of pre-contact indigenous and modern industrialized fisheries in northern British Columbia, Canada.

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THE RELEVANCE OF COHESIVE STRUCTURES IN THE SELF-ORGANIZATION OF MARINE ECOSYSTEMS

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ABSTRACT

One of the issues that have drawn the attention of ecologists is how ecosystems that are both complex and stable are organized. It has been argued that ecosystems have regulatory mechanisms that optimize their structure and function. These mechanisms are known as self-organizing processes that are regulated by environmental forcing factors. In this way, ecosystems existence endures in the long-term in often-hostile environments. However, ecosystem dynamics change over time depending on environmental conditions. It has been observed that recovery of ecosystem is enhanced when hostile conditions end up. Graph theory suggests that cohesive structures play a relevant role in the resilience of networks (artificial or natural). Here, we use two marine food webs to analyse the existence of substructures that contribute to maintain and preserve the ecosystem. The first one is Terminos Lagoon (TL) in the southern Gulf of Mexico and the other is the Sinaloa Continental Shelf (SCS) at the Central Mexican Pacific. We use these as case studies because we have Ecopath trophic models for both of them representing periods with different environmental conditions.

For TL we have three models representing 1980, 1998 and 2011 years. Differences in environmental conditions as indicated by climate variability at the southern Gulf of Mexico have been reported for those years (Del Monte-Luna 2012; Arreguín-Sánchez et al. 2008). For SCS we have two models 1995 and 2007 years that also represent different environmental periods (Hernández-Padilla, 2012).

First, we compare summary trophic flows and network indices to identify differences in ecosystem function related with environmental conditions. Then, in order to search for cohesive substructures during different environmental conditions we use the clique concept. A clique is a set of nodes where every element of the set is connected to every other member. In this sense a clique is a substructure of functional groups that are more intensively related among them, than they are with other members of the food web.

In the case of TL, most energy flows decreased by 40% in 1998 and 58% in 2011, when compared to 1980. There were also differences between years in transfer efficiency among trophic levels. Additionally, the ecosystem organization decreased, as measured by ascendency/development capacity, with 11% in 1998 and 7% in 2011, relative to 1980. In SCS, we found that the total system throughputs were decreased by

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20% in 2007, relative to 1995. The average transfer efficiencies between trophic level were also different between years. Conversely, the organization of the ecosystem was 14% higher in 2007 compared to 1995. These results suggest different functional status of both ecosystems during the periods analysed.

The analysis of substructures, however, indicated that there are certain groups at different trophic levels that conform cohesive structures and remain constant over time for both ecosystems. In the case of TL, cliques conformed mainly by seagrasses, microcrustaceans, meiothons, echinoderms, and some fishes were prevailing during all the three years studied; the structure is maintained because there are substructures that have remained relatively stable, and which are associated with ecosystem stability. In the case of SCS, cliques were conformed by macrophytes, shrimps, zooplankton, some fish groups and seabirds.

Finally, we discuss the relevance of substructures in marine food webs. Krause et al. (2003) indicates that compartments or substructures are related to stability in networks. Alon et al. (2007) suggest that the identification of recurrent network interconnections is important to understand network evolution because substructures perform relevant functions. Future work will address how climate forces affect ecosystem function and substructures through dynamic simulations.

ACKNOWLEDGEMENTS
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REFERENCES
A META-ANALYSIS OF ECOSYSTEMS’ TROPHIC FUNCTIONING: IDENTIFICATION OF TYPICAL TROPHIC BEHAVIOR AND ASSOCIATED RESPONSES TO FISHING IMPACT

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ABSTRACT
The variability in food web dynamic across an array of marine ecosystems has been explored for many decades. New insights into trophic functioning have been made possible thanks to ecosystem modeling. Indeed, several studies have shown that trophic functioning and fishing impacts on ecosystem structure differ depending on the various characteristics of ecosystems in question (Christensen and Pauly, 1993; Coll and Libralato, 2012; Heymans et al., 2012, 2014). The Ecopath with Ecosim software and model (EwE; Christensen and Walters, 2004) is used worldwide to analyze trophic interactions and quantify trophic flows in aquatic ecosystems. Yet, to date, only a handful of studies used these models to extract global trends and patterns. EcoTroph (ET) is a recent approach and software for modeling marine and freshwater ecosystems, entirely articulated around the TL concept (Gascue and Gascuel, 2013; Gascue and Pauly, 2009; Gascue et al., 2011). It enables notably the construction of a unique framework for EwE models comparison, the trophic spectrum. We focused on these two trophodynamic models to examine the trophic functioning of marine ecosystems by identifying typical trophic behavior and associated responses to fishing impact.

We extracted 190 EwE models from the EcoBase repository (Colléter et al., 2013). These models were associated with their geographic coordinates, and a-priori classified according to their location (tropical, temperate, polar), and ecosystem type. We distinguished six important marine ecosystem types for our analysis: bay/fjord, coastal lagoon, coral reef, continental shelf, upwelling, and ocean. We tested statistically significant differences between ecosystem types regarding functioning key parameters calculated by EwE, particularly the transfer efficiency, and proportion of flow originating from detritus. Using ET, mean trophic spectrum computations were done for each ecosystem class using bootstrap procedures. The associated key parameters were calculated and statistically compared, as their resistance to different fishing scenarios. Finally, we tested the relation between abiotic data (temperature, spatial coordinates, depth, and primary production) and functioning key parameters.

Our results showed significant differences of trophic functioning between ecosystem types. The transfer efficiency (TE) key parameter differed for our six categories with significantly different fast trophic kinetics in upwelling ecosystems (5%), and slow ones in coral reefs (14%). The proportion of flows originating from detritus also differed between ecosystem types with much higher values corresponding to
more than a half for coastal lagoon and coral reef ecosystem types (respectively 50% and 58%). On the other hand, upwelling ecosystems relied lightly on this benthic production with only a quarter of flows originating from detritus. We explored and identified general relationships linking trophic functioning key parameters to abiotic variables (e.g. linking transfer efficiencies and latitudes). We also computed the mean trophic spectra by ecosystem type and found the same significant results. Finally, using these mean trophic spectra, we showed significantly different responses to fishing impact between ecosystem types. For example, looking at the accessible biomass (Bacc/Bacc,virgin), upwelling ecosystems are more resistant to fishing impacts while coral reef ecosystems are intrinsically more fragile.

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Scientific advice for management

ECOSYSTEM EVOLUTION AND CHALLENGES FOR MANAGEMENT: POSTER PRESENTATIONS

THE USE OF ECOSPACE MODEL AS A SIMULATION TOOL FOR FISHERIES MANAGEMENT PLANS: CASE OF THE GULF OF GABES

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ABSTRACT

The Gulf of Gabes is considered as one of the most productive areas of the southern Mediterranean Sea and it plays an important role in Tunisian economy, this region is mostly characterized by a large continental shelf, reaching only 50m depth at 110km offshore. Furthermore, the gulf of Gabes is considered as an archetypal ecosystem in which the effects of fisheries are the most pronounced. Based on the stock assessment outcomes, it is considered as a highly exploited ecosystem.

Thereupon, it becomes necessary to establish some adequate measures in order to facilitate the recovery of the marine resources. The most important sets of these measures are the temporal trawl nets closures and the establishment of Marine Protected Areas which are permanent or temporal spatial closures. However, these management plans should be assessed beforehand, in a way to have an idea about the potential effects of the measure put in place.

Using Ecospace (Christensen, 2005), we investigated the potential impacts of several spatial and temporal management scenarios on the ecosystem functioning of the exploited continental shelf of the Gulf of Gabes. The Ecospace model is based on the existing Ecopath model (Hattab, 2013) which includes 41 functional groups and 6 fisheries.

The transition from Ecopath model to the spatial model requires the definition of additional parameters for each functional group, such as the dispersal rates, the dispersal rates in bad habitats, the vulnerability to predation in bad habitat and the feeding rate in bad habitat. In this study we defined 12 habitats based on the bottom type and the depth strata. Afterwards, each one of the 41 functional groups was assigned to its preferred habitat based on available information about the ecology and the biology of species. Concerning the fishing effort, it’s necessary to precise, for each fleet, the habitats in which it can occur.

In the present study, we simulated several scenarios over a 15-year period, between 1995 and 2010. The management scenarios used were elaborated based on a field survey among fishermen results and on expert’s opinion. These plans are divided into two principal types of fishing restrictions, 4 scenarios regarding different marine protected areas establishment, and 4 scenarios concerning the implementation of biological rest-periods (seasonal closures).

**Table 1. Ecospace model characteristics**

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</table>

Figure 1 illustrates the spatial distribution of the 41 functional group after a simulation over 15 years and under the baseline scenario, the color scale, on the right, indicating an increase of biomass (red) or a decrease of biomass (blue) compared to the biomass at the start of the 15-year run. Considering the outcomes of management scenarios simulations, we can approve that marine protected areas, as well as seasonal closures, have a positive impact on the several commercial species and predatory organisms. In fact the biomass of these functional groups showed a significant increase. Although, the biomass of some other groups showed a decrease, that can be explained by the trophic cascade.

Moreover, we noticed positive effects of fishery management plans on the harvested biomass for several groups. On that, some of the scenarios tested are beneficial for the ecosystem integrity and for the fishermen at the same time, and others were not so beneficial.

**Figure 1.** Spatial distribution of functional groups under baseline scenario.
ACKNOWLEDGEMENTS

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DEVELOPING SCIENTIFIC CAPACITIES THROUGH INTERNATIONAL COLLABORATION FOR ECOSYSTEM-BASED MANAGEMENT OF MARINE RESOURCES FACING CLIMATE CHANGE: MEXICO, URUGUAY AND COLOMBIA\textsuperscript{45}

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ABSTRACT

Currently, scientific advice for fisheries management is mainly based on the population concept. Population models assume, implicitly or explicitly, a stable carrying capacity and that fishing is the main driver of stock abundance. However, at present, in the face of climate change and other human-induced pressures affecting entire ecosystems, the assumption of a constant carrying capacity is no longer valid. Under the population concept, the relationship between environmental variability and trophic dynamics is largely disregarded, and thus decreasing the probability of success of conventional management advice. "Ecosystem-based fisheries management" (EBFM) is recognized as an approach that could provide a better understanding of ecosystem dynamics, improving scientific support for management of fisheries and biological conservation (Pikitch et al. 2004). However, because holistic attributes of ecosystem dynamics are not tangible for managers and stakeholders, the application of direct management measures has rely on single-fisheries (single-stocks) taken ecosystem information as a general framework. This scientific challenge was recognized and collaborative efforts to promote the EBFM approach in Latin America have been fostered between México, Uruguay and Colombia. The project “Development of scientific capacities through international collaboration for ecosystem-based management of marine resources to climate change: Mexico, Uruguay and Colombia” sponsored by the Uruguayan and Mexican Governments, joins a number of scientists for investigating the use of trophic models to analyze the state of marine ecosystems. In particular fishing thresholds are estimated applying the concept of “ecosystem limit reference level” (Arreguín-Sánchez et al, this volume). Several ecosystem models are used as case studies on the project: The southern coast of Sinaloa, in the Gulf of California, México; the estuary of Río de la Plata, Uruguay; and an upwelling ecosystem in the Caribbean Sea off Colombia.

Research work will be developed along the three years that lasts the project, and comprises several steps based on the suite of programs Ecopath with Ecosim: i) Improvement of existing Ecopath models; ii) Calibration of the dynamic model with time series of observed abundances (biomasses), fishing effort and forcing variables (sea surface temperature and other climate indices). The results will be a model representing the recent history of the ecosystem (last 60 years), which will be taken as base line for testing hypotheses, and a picture of the evolution of the ecosystem along the simulated time period (see for example Figure 1); iii) simulation experiments.

Based on simulation experiments, we will compute the response of the ecosystem to a progressive loss of biomass. From this, the base Ecopath model will be modified to reconstruct a model without any loss of biomass (e.g. without fishing); then biomass will be extracted from the model at a continuous rate for a specified period, and ecosystem response will be measured in terms of the Ascendency/Capacity ratio (sensu Ulanowicz 1986) that represents ecosystem order, where the gain in entropy is denoted by 1-A/C. This operation will be developed for all the trophic groups in the ecosystem. In parallel, we will compute the ecosystem resilience based in trophic data, particularly the consumption matrix of the ecosystem (Arreguín-Sánchez, 2014). This computation will be made for all the years along the simulated period.

A diagram expressing the loss of order (gain in entropy; ecosystem degradation) will be developed; this consists in a picture where the gain in entropy is related to tropic levels (functional groups), as function of the rate of loss of biomass (or harvest rate representing the percent of biomass extracted; Figure 2). Interpretation of this diagram requires the identification of a critical level of degradation representing the maximum degradation of the ecosystem that can be accepted by manager (in analogy to a risk analysis). In our case (to prevent an arbitrary selection), since entropy is related
to 1 - A/C, we can establish the relationship between resilience and A/C so that the critical limit can be defined, for example, by the lowest value of resilience considering the ecosystem evolution along the simulated period. This level is defined as ecosystem limit reference level. Its interpretation is simple, for a given tropic group (tropic level) we can intercept these isolines and observe the correspondent value of harvesting rate. Such harvesting rate, since represent the percent of the biomass removed can be identified as the limit of fishing. Such limit of fishing can be computed for all the groups of the ecosystem.

Based in the above outputs we will project different scenarios, for example, climate change for a given period (i.e. ~10 years) and identify needs of adaptation of fishing strategies in order to maintain the sustainability of the ecosystem. Results will be compared between Latin American ecosystems and related to the regional or local context, in term of both strategies for resource exploitation and climate change scenarios.

ACKNOWLEDGEMENTS

We acknowledge support by the governments of Mexico and Uruguay through AMEXCID and AUCI, respectively.

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**ECOSYSTEM CHANGES AND “ECOSYSTEM LIMIT REFERENCE LEVEL” FOR SUSTAINABLE FISHERIES: THE CAMPECHE BANK MEXICO AS STUDY CASE**

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**ABSTRACT**

Currently, the scientific advice for fisheries management is based on the population concept. Population models assume, implicitly or explicitly, a stable carrying capacity and that fishing is the main driver of changes in stock abundance. However, at the present, due to climate change, global warming or even other human induced changes, the assumption of a stable carrying capacity is not valid any more. At the present, under the population concept, and since the environment is changing steadily, uncertainty increases, and the probability of success of management advice decreases due to the explained variance is lower with respect to the stable state. With a changing environment, population’s dynamics changes as well as ecosystem since the interdependencies among populations also change. The concept “ecosystem based fisheries management” (EBFM) is recognized as the approach that could provide a better understanding of ecosystem dynamics resulting in a better scientific baseline for fisheries management. However, at the moment, ecosystem information is only taken as framework for management of single fish stocks.

In Mexico, the National Fishing Act, NFA (DOF 2012), is the instrument of the federal government where the state of the fisheries is declared. This document is the reference for the fishing sector since indicates objectives and management measures to be applied, levels of effort to apply in each case, closures in time and space, minimum legal sizes, etc.; all of them based in the population concept. The Campeche Bank is a region where some of the most important fish stocks are declared as overfished (Farfantepenaeus duorarum) fishery were obtained about late 1950’s to early 1970’s reaching around 21,000 t per year, and declining at the present to about 1,200 t. Annual yields for the red grouper (Epinephelus morio) were about 18,000 t by the early 1970’s, being at the present about 8,000 t. The red snapper (Lutjanus campechanus) is reported as deteriorated, and the hawksbill turtle (Eretmochelys imbricata), even when is not exploited, declined drastically by the mid 1990’s. Other stocks declared as fully exploited are, snook (Centropomus undecimalis), sharks (several species), lobster (Panulirus argus) and octopus (mainly Octopus maya), among others, being the last the only presenting an increase in annual yields, from ca. 7,000 t in mid 1980’s to 18,000 t last decade. However, independently of the state of exploitation, all stocks exhibit a significant relationship with several environmental variables in the last six decades suggesting a strong effect of climate change, which was confirmed from our analyses on the SST anomalies in the Gulf of Mexico, where we found that, for the Campeche Bank, the harmonic component of 67 years explains more that 60% of the variation of temperature (del Monte-Luna 2014).

*Figure 1.* - Trend of the anomaly of SST (thin line) and changes in relative production along the evolution of the ecosystem, showing the effect of climate change on the Campeche Bank (higher production is in red and lower in yellow). Note that regime shift can be identified about mid 1970’s. Production increases with cooling trend and decreasing with increase in temperature (adapted from Arreguín-Sánchez et al. 2014).

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Based on Ecosim, using the Sea Surface Temperature (SST) anomaly as forcing factor on primary producers (and inversely on octopus), and the time series of relative abundance and effort for 18 fish stocks, we reconstructed the recent evolution of the ecosystem (1956 to 2010) where we can observe changes in ecosystem production associated with climate change (figure 1).

Simulation experiments were developed to explore ecosystem degradation because the loss of biomass; where, for each functional group, independently each other, biomass was extracted as a constant rate for a period of 50 years. Results are expressed in Figure 2 as the degree of ecosystem degradation (gain in entropy) as a function of the loss of biomass (harvesting rate) and species (trophic level).

Black line on right in Figure 2 represents the “ecosystem limit reference level”, ELRL, as the risk for ecosystem degradation due the loss of biomass represented by the harvesting rate. For example, for a high trophic level the maximum limit of biomass extracted by fishing (limit of catch) is defined by a harvesting rate (C/B) of about 0.32 (yellow arrow); while for an intermediate trophic level of 3.2 the harvesting rate will be about 0.40 (white arrow). The critical issue in the diagram is how such risk represented by the ELRL can be defined. Our research can demonstrate that such criteria can be found from the minimum historical level of resilience estimated from consumption data Arreguín-Sánchez 2014), which can be associated directly with the gain in entropy (1-A/C).

Evidences indicate that many of the trends observed in fish stocks in the Campeche Bank are consequence of both, climate and fishing, being the reason because measures emanated from conventional management have little success. The proposed “ecosystem limit reference level” concept appears to be a convenient approach to identify limits of fishing for individual fish stocks based on holistic attributes of ecosystems.

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AN ECOSYSTEM APPROACH TO THE ROLE OF FISH FARMING IN COASTAL AREAS

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ABSTRACT

Coastal ecosystems put up most of the impacts from human activities in the sea. Generally, assessment based on a unispecific ecological group and/or habitat reflects only a fraction of what is happening in the ecosystem, and usually it is biased by the spatial and temporal variability at small scales. This is more evident when several human activities co-exist in the same area and interact synergically among them and with the natural structure and dynamics of the ecosystem. An ecosystemic assessment can combine several ecological groups, habitats, processes and/or activities, and offer a more holistic picture about the structure and dynamics of the considered coastal area.

Coastal intensive fish farming is wide spreading over the world, producing more than 20 million tonnes of fish per year. In the Mediterranean Sea, the number of fish farms has increased dramatically from early '80 in coastal waters (Ferlin and LaCoix, 2000), adding a new source of impacts (see Holmer et al. 2008 for a review). Fish farming release a substantial amount of nutrients (in both forms of organic matter and artificial food pellets), modifying the habitat and communities beneath cages and favouring aggregations of wild fish around the cages (Sánchez-Jerez et al. 2011). As a result, fish farming generates a large flux of organic matter, acting food pellets as a key factor fueling the ecosystem (Bayle-Sempere et al. 2013). It triggers several direct and indirect impacts in the ecosystem, which are not always evident from a single point of view.

Some ecological processes can be affected by the presence of fish farming which need a precise assessment in order to maintain the ecological status of any coastal area. Some of the potential applications and benefits of our holistic approach for a sustainable coastal management could be to:

- Estimate the carrying capacity of the system regarding the critical production suitable for a certain area. It would be one of the most important issues pointing towards the sustainable management of coastal zones.
- Estimate both the levels of escapees in the environment and the critical threshold bearable by the surrounding ecosystem in addition to estimate a level of fishing effort capable to control the incidence of escapees to affordable levels for the environment. Altogether will help to minimize...
the negative influence (habitat competition, genetic flow, etc...) of escapees over wild counterparts of the cultured species and/or other wild fish.

- Assess the effects of aggregated top predators on the structure and dynamics of the considered ecosystem in order to warn about undesired negative impacts on key commercial species.

EwE can be a valuable tool for understanding the effects of fish farming and predict changes on biodiversity, commercial fisheries or socio-economic activities like tourism or sport fishing. Modeled results will allow the design of reliable short-term fish farming management at the scale of the whole ecosystem considered. Combining these with the results from unspecific studies would help to enrich the simulated output by including procedures from statistical learning in order to estimate variability, standard errors and confidence intervals to the simulated data.

In our particular case, we present a first approach to assess the possible impact of fish farms on the ecosystem through changes in resilience. The hypothesis is that if resilience is affected, the level of disturbance may be estimated and thus the sustainability of the ecosystem. The findings of this experiment will be useful to formulate potential experiments and address the above questions.

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REFERENCES


**Scientific advice for management**

**WASP-WAIST CONTROL ON FOOD WEB OF A TROPICAL FRESHWATER RESERVOIR**

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**ABSTRACT**

The understanding of food web controls (top-down, bottom-up, wasp-waist, alternated) is a tool to support fisheries management strategies that are related to ecosystem development and species biomass of brackish or freshwater ecosystems (Griffiths et al., 2013). Sítios Novos reservoir (Ceará State, Brazil) is a freshwater ecosystem built for fishery and water supply in a region under semiarid conditions with severe dry seasons. The reservoir area and volume are respectively 16.4811 km² and 126.106 m³. Many fish species were introduced in this ecosystem to try increasing a small-scale fisheries: *Oreochromis niloticus* is described as primarily herbivorous but could increase feeding on benthos especially in long dry seasons (Njiru et al., 2004), *Atherinella brasiliensis* a brackish estuarine fish species feeding on zooplankton, detritus and invertebrates (Contente et al., 2011) and *Cichla monoculus* a piscivorous top predator. Furthermore, *Melanoides tuberculata* is a snail alien species feeding on around vegetation and detritus. This species is a bioinvader probably introduced in Brazil by aquarium trade. Nowadays, the species has the widest macrobenthic distribution on Brazilian reservoirs (Lima et al., 2013). To comprehend the role of these fish and invertebrate species on the food web of Sítios Novos reservoir, we develop an Ecopath model. Our premise is that the influence of intermediate fish groups *A. brasiliensis* and *O. niloticus* about the trophic food web control changes from bottom-up control to wasp-waist control in this ecosystem.

### Table 1. Diet composition of thirteen functional groups in Sítios Novos reservoir from June, 2013 to March, 2014.

<table>
<thead>
<tr>
<th>Group name</th>
<th>TL</th>
<th>B</th>
<th>P/B</th>
<th>Q/B</th>
<th>EE</th>
<th>P/Q</th>
<th>KS</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytoplankton</td>
<td>1.00</td>
<td>141.01</td>
<td>2.50</td>
<td>0.00</td>
<td>0.25</td>
<td>-0.65</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Copepoda</td>
<td>2.00</td>
<td>2.45</td>
<td>6.00</td>
<td>15.00</td>
<td>0.86</td>
<td>0.40</td>
<td>-0.53</td>
<td>0.26</td>
</tr>
<tr>
<td>Cladocera</td>
<td>2.00</td>
<td>0.67</td>
<td>12.00</td>
<td>30.00</td>
<td>0.78</td>
<td>0.40</td>
<td>-0.75</td>
<td>0.16</td>
</tr>
<tr>
<td>Rotifera</td>
<td>2.00</td>
<td>2.65</td>
<td>24.00</td>
<td>60.00</td>
<td>0.17</td>
<td>0.40</td>
<td>-0.33</td>
<td>0.42</td>
</tr>
<tr>
<td>Ostracoda</td>
<td>2.00</td>
<td>3.47</td>
<td>4.60</td>
<td>9.40</td>
<td>0.84</td>
<td>0.49</td>
<td>-0.71</td>
<td>0.18</td>
</tr>
<tr>
<td>Chironomidae larvae</td>
<td>2.00</td>
<td>2.66</td>
<td>10.55</td>
<td>42.22</td>
<td>0.48</td>
<td>0.25</td>
<td>-0.30</td>
<td>0.45</td>
</tr>
<tr>
<td><em>M. tuberculata</em></td>
<td>2.00</td>
<td>77.40</td>
<td>4.82</td>
<td>13.43</td>
<td>0.11</td>
<td>0.36</td>
<td>-0.35</td>
<td>0.58</td>
</tr>
<tr>
<td>Other invertebrates</td>
<td>2.00</td>
<td>5.03</td>
<td>2.62</td>
<td>26.00</td>
<td>0.35</td>
<td>0.10</td>
<td>-0.65</td>
<td>0.20</td>
</tr>
<tr>
<td><em>A. brasiliensis</em> juvenile</td>
<td>2.86</td>
<td>0.69</td>
<td>8.02</td>
<td>49.09</td>
<td>0.09</td>
<td>0.16</td>
<td>-0.17</td>
<td>0.60</td>
</tr>
<tr>
<td><em>A. brasiliensis</em> adult</td>
<td>2.86</td>
<td>1.50</td>
<td>1.80</td>
<td>11.91</td>
<td>0.14</td>
<td>0.15</td>
<td>-0.35</td>
<td>0.39</td>
</tr>
<tr>
<td><em>O. niloticus</em> juvenile</td>
<td>2.44</td>
<td>0.45</td>
<td>1.60</td>
<td>41.88</td>
<td>0.32</td>
<td>0.04</td>
<td>-0.49</td>
<td>0.29</td>
</tr>
<tr>
<td><em>O. niloticus</em> adult</td>
<td>2.65</td>
<td>2.95</td>
<td>1.11</td>
<td>16.71</td>
<td>0.56</td>
<td>0.07</td>
<td>-0.20</td>
<td>0.56</td>
</tr>
<tr>
<td>C. monoculus juvenile</td>
<td>2.86</td>
<td>0.35</td>
<td>1.59</td>
<td>10.70</td>
<td>0.33</td>
<td>0.14</td>
<td>-0.73</td>
<td>0.16</td>
</tr>
<tr>
<td>C. monoculus adult</td>
<td>3.56</td>
<td>0.29</td>
<td>1.32</td>
<td>5.26</td>
<td>0.76</td>
<td>0.25</td>
<td>0.053</td>
<td>1.00</td>
</tr>
<tr>
<td>Detritus</td>
<td>1.00</td>
<td>1750</td>
<td>1.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TrophicLevel (TL), biomass.m⁻² (B), production.biomass⁻¹.year⁻¹ (P/B), consumption.biomass⁻¹.year⁻¹ (Q/B), production.consumption⁻¹.year⁻¹ (P/Q), ecotrophic efficiency (EE), keystoneness index (KS) and relative total Impact (RI).
Table 1 shows the main results of Ecopath analysis and also the keystone index (KS) and the relative impact (RI) on food web of each compartment (Libralato et al. 2006). Keystoneness groups are *C. monoculus* (0.053) and *O. niloticus* (-0.20) adults. Bottom-up relative total impacts are strongest on *C. monoculus* adults (1.00) and *A. brasiliensis* juvenile (0.60).

Figure 1 illustrates a Lindeman spine with trophic chain and showing the trophic level II (TLII) consumptions is higher by detritus chain than Primary production (P) in a ratio 18:1 (D:PP).

Libralato et al. (2006) showed a trophic food web importance of these intermediate functional groups on upwelling ecosystems keystoneness index. In that sense, highest productivities in Sítios Novos reservoir that was found to be supereutrophic to hypereutrophic in the period 2010-2011 (Bezerra et al., 2014) makes it favorable to wasp-waist control by *A. brasiliensis* and by *O. niloticus*.

*A. brasiliensis* juveniles (TL=2.80) influences wasp-waist control by a top-down plankton-feeding control specially on Copepoda and Ostracoda, at the same time that exerts a bottom-up control on piscivorous *C. monoculus*. *A. brasiliensis* juveniles and *C. monoculus* (respectively, highest ecosystem RI and lowest ecosystem KS) represents the positive influence of intermediate prey groups on top predator diet and on plankton predation.

*M. tuberculata* highest biomass on Sítios Novos reservoir is related to its opportunism, resistance to desiccation and rapidly environment widespread (Callisto et al., 2005). This snail biomass availability increases the *O. niloticus* niche breadth, an opportunity that has been utilized, since there are no aquatic macrophytes at reservoir, limiting insect biomass availability (Njiru et al., 2004). This is represented by *O. niloticus* adults with small KS and high RI. Finally, we conclude that *A. brasiliensis* and *O. niloticus* are contributing for wasp-waist control more than bottom-up control on this freshwater ecosystem.

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We would like to thank the staff of Aquatic Ecology Laboratory (Laboratório de Ecologia Aquática/UFC) for support, and project PPP/FUNCAP (Fundação Cearense de Apoio ao Desenvolvimento Científico e Tecnológico - GPF 2153/85) for equipment and supplies.

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A COMPARATIVE ANALYSIS ON THE ECOSYSTEM STRUCTURE AND FUNCTIONING OF FOUR REGIONAL SEAS OF TURKEY (BLACK SEA, MARMARA, AEGEAN AND THE MEDITERRANEAN) 49

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ABSTRACT

The Black Sea, the Sea of Marmara, the Aegean Sea and the Mediterranean Sea are partially connected but contrasting ecosystems. In addition to significant variations in their physical and biogeochemical characteristics, they house distinct fish assemblages which have been exploited by independent fishing fleets. This study aims to investigate the gradient between the structure and functioning of the Black Sea, the Marmara Sea, the Aegean Sea and the Mediterranean Sea ecosystems by using Ecopath with Ecosim. For this aim, four EwE models were set up in the regional Turkish EEZs’ between the years 1990-2010. A total of 44 important fish species were selected among the 71 commercially-exploited fish species that sum up to 96%, 91%, 78% and 68% of the 20-year total Turkish landings from the Black Sea, the Marmara Sea, the Aegean Sea and the Mediterranean Sea, respectively. Afterwards, the fish species were grouped into 24 functional groups based on the similarities/differences in their habitat and food preferences. Finally, regional EwE models were constructed from 10 functional fish groups in the Black Sea, 13 in the Marmara Sea, 14 in the Aegean Sea and 15 in the Mediterranean Sea. In addition to phytoplankton, zooplankton and detritus functional groups, the Black Sea and Marmara Sea models also included four different jellyfish groups.

Results showed that the higher biomass proportions accumulated in the first and second trophic levels of the Black Sea shifted to accumulate in the third and fourth trophic levels of the food chain towards the Mediterranean Sea. Keystone analyses displayed that different fish species played structuring roles in each of the four regional ecosystems. Mixed trophic impact analysis demonstrated the unique interactions between the ecosystem components of each ecosystem as well as the impacts of fisheries on contrasting functional groups in each region.

This study provided a contribution to the understanding of the structure and functioning of the partially-connected Turkish regional marine ecosystems. It is believed that the specific differences and priorities of the regional marine ecosystems assessed in this study will provide recommendations for the future Ecosystem-Based Fisheries Management (EBFM) options in the four Turkish seas.

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This study was carried out with partial support of TUBITAK 113Y040 Project and METU-CARES / Center for Marine Ecosystems and Climate Research Project (CMECLIM).
MANAGEMENT OF AQUATIC ECOSYSTEMS EXPLOITED BY ADAPTABILITY AND SUSTAINABILITY: THE CASE OF FISHERIES IN SINALOA, MEXICO

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ABSTRACT
Management of exploited aquatic resources is not easy; it is even considered an art (González Laxe, 2002). This is a very complex issue especially if we consider the different interactions between the exploited resources such as trophic relationships, environmental changes and social pressures. The ecosystem is subject to different pressures such as overfishing (Fogarty and Murawski, 1998; Hobson and Lenarz, 1977). This aspect can accelerate the loss of marine biodiversity in the long term. Most fishery models were developed between 1950 and 1980 where the environmental conditions were relatively stable, and therefore, we assumed that fishing was the main source of variations in the abundance of exploited populations. Currently the environmental conditions are not stable thus this assumption is not valid, emerging the need for adaptable strategies for sustainable fisheries management. The ecosystem responds to these pressures in different ways according with its capacity of self-organization (Ulanowicz et al., 2009). These processes refer to the sustainability of the resources exploited in the medium and long term.

The aim of this paper is to contribute comprehensive information and evaluate scenarios to support management of sustainable use of the resources in the ecosystem. We use as a case study the fisheries of the continental shelf of southern Sinaloa, Mexico. Simulations such as climate change are proposed to evaluate the sustainability indicator (self-organization) and adaptability of fisheries management. The baseline to compare these simulations was the trophic model representing ecosystem’s conditions in the period 2006/07 (Hernández-Padilla, 2012). The projection of 100 years of the trend of climate change IPCC A1B model was used. Ecopath and Ecosim models were the base for exploration and identification of ecosystem indicators.

Figure 1. Trajectory of change sustainability indicator as the effect of climate change.

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Preliminary results suggest that the trajectory of change with respect to the values of sustainability indicator (0.90 to 0.82) of the current state of the ecosystem (period 2006-2011), shows a certain trend to gain in entropy, indicating a loss of self-organization capacity. However, this does not necessarily mean ecosystem degradation. Conversely, considering the effect of environmental variability particularly the effect of climate change, the values of sustainability indicator (0.90 to 0.58) also trend toward the gain in entropy, representing the origin of the self-organization curve in Figure 1. The loss ecosystem’s organization suggests a vulnerable ecosystem to external perturbations. This could be interpreted as evidence of the effect of climate change on the ecosystem sustainability. In order to address this condition, the measures of management and control of fishing mortality should be more efficient to maintain sustainability.

With the series of sustainability indicator or potential self-organization (to 2100), ecosystem evolution is shown under the scope of this indicator. The trend suggests a decrease on ecosystem’s self-organization capacity and a greater variability between period 2006-2038 as a result of climate change considered in the simulation experiment (IPCC’s model). Following on from these series, we identify four alternative ecosystem states (2006-2018, 2019-28, 2029-2037 and 2038-2100; Figure 2) given by similar values of sustainability indicator which can adopt different management strategies.

Finally, the concept of adaptability as a management strategy is a key concept linked to the ecosystem’s sustainability. We should be able to adjust catch rates of exploited resources to the different alternative states of ecosystem for sustainability of exploited marine resources.

ACKNOWLEDGEMENTS

First author thanks the Instituto Politécnico Nacional (CICIMAR-IPN) for contributions and support, CONACyT for scholarships. Thanks also the projects SEP-CONACyT 155900; as well as the support by Governments of Mexico and Uruguay through the AUCI and AMEXCID. The 2nd ans 3rd authors recognize support by IPN through programs EDI and COFAA.

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ABSTRACT

Fishing in Amazon basin involves approximately 350,000 fishermen who are responsible for an annual production of 166,477 tonnes of fish (MPA, 2010). Madeira River, one of the biggest Amazon Rivers, has a basin area estimated in 1,380,000 km² (Goulding et al., 2003) and comprises about 1,500 fish species (Ohara et al., 2013). Recently, the Medium Madeira River was widely dammed offering an opportunity to understand environmental impacts in a multidisciplinary approach. Accordingly, a modeling for Madeira River was performed using dataset for 4 years before the dam closure and was used to compare with ecological predictions for post-dam scenario. Additionally impoundment was simulated using the Ecopath's forcing functions.

The Ecopath for Madeira River has 49 components (see table 3) selected by: i) main landings; ii) diet composition for main fish species; iii) non-fish compartments and iv) grouping fish species: Carnivores, Detritivores, Insectivores, Omnivores, Piscivores, Herbivores. We also used three fishing fleets: commercial landings, local consumption, fish locally sold by riverine people.

System attributes for Madeira River Model indicates high resilience and maturity (Table 1).

Table 1. Ecosystem Attributes for Madeira River.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flow system</td>
<td>11452.9</td>
<td>t km⁻² per year</td>
</tr>
<tr>
<td>Primary production/total respiration</td>
<td>0.632</td>
<td></td>
</tr>
<tr>
<td>Total biomass/Total flow</td>
<td>0.744</td>
<td></td>
</tr>
<tr>
<td>Total biomass (excl. detritus)</td>
<td>8528.159</td>
<td>t km⁻²</td>
</tr>
<tr>
<td>Connectance index</td>
<td>0.131</td>
<td></td>
</tr>
<tr>
<td>Total catch</td>
<td>0.4411</td>
<td>t km⁻²</td>
</tr>
<tr>
<td>Trophic level of fishery</td>
<td>2.60</td>
<td></td>
</tr>
<tr>
<td>Systems omnivory index</td>
<td>0.180</td>
<td></td>
</tr>
<tr>
<td>Transfer efficiency</td>
<td>5.4</td>
<td>%</td>
</tr>
<tr>
<td>Finn cycling index</td>
<td>18.29</td>
<td>%</td>
</tr>
<tr>
<td>Ascendancy</td>
<td>36.1</td>
<td>%</td>
</tr>
<tr>
<td>Overhead</td>
<td>63.9</td>
<td>%</td>
</tr>
</tbody>
</table>

---

Trophic chain is much more influenced by detritus than by primary producers. Key-species have intermediate and high trophic levels and they are non-fish compartments, showing the importance of non-fish compartments to the system (Table 2). We also simulated the dam’s impact using water level as a forcing function in Ecopath with Ecosim. Firstly seasonal water level was simulated by four years and after the forcing function was maintained in high level indicating that the majority of species could be negatively impacted and that the total catch would be reduced by 27% (Table 3). The main impact identified was on fish migration (mainly for catfish). But the increase in turbidity and suspended solids may hamper predation exerted by all piscivores and the change in the natural course of the river may negatively impact all species. This result will be validated by Ecopath model post-impoundment and will allow a broad understanding on the impact simulation using forcing function.

**Table 2.** Main key-species of the Madeira River ecosystem.

<table>
<thead>
<tr>
<th>Key-species</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Other Piscivores</td>
<td>0.154</td>
</tr>
<tr>
<td>2 Waterfowl</td>
<td>0.0422</td>
</tr>
<tr>
<td>3 Copepoda</td>
<td>0.00566</td>
</tr>
<tr>
<td>4 Dolphins</td>
<td>-0.0409</td>
</tr>
<tr>
<td>5 Cichla pleioidana</td>
<td>-0.056</td>
</tr>
<tr>
<td>6 Terrestrial Invertebrate</td>
<td>-0.0819</td>
</tr>
<tr>
<td>7 Astronotus crassipinnis</td>
<td>-0.131</td>
</tr>
</tbody>
</table>

**Table 3.** Simulation of impoundment on Madeira River model using Ecopath’s forcing function. Values in (%) represent the changes in relation to original biomass and catch.

<table>
<thead>
<tr>
<th>N</th>
<th>Compartments</th>
<th>Biomass (%)</th>
<th>Catch (%)</th>
<th>N</th>
<th>Compartments</th>
<th>Biomass (%)</th>
<th>Catch (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Phytoplankton</td>
<td>-46.68</td>
<td>25</td>
<td>25</td>
<td>Cichla pleioidana</td>
<td>-24.67</td>
<td>-24.8</td>
</tr>
<tr>
<td>2</td>
<td>Floodplain Forest</td>
<td>-4.75</td>
<td>26</td>
<td>26</td>
<td>Schizodan fasciatus</td>
<td>-3.44</td>
<td>-3.62</td>
</tr>
<tr>
<td>3</td>
<td>Macrophytes</td>
<td>-74.41</td>
<td>27</td>
<td>27</td>
<td>Brachyplatystoma platynemun</td>
<td>-16.72</td>
<td>-16.92</td>
</tr>
<tr>
<td>4</td>
<td>Periphyton</td>
<td>-76.98</td>
<td>28</td>
<td>28</td>
<td>Potamorhina latior</td>
<td>-63.04</td>
<td>-63.13</td>
</tr>
<tr>
<td>5</td>
<td>Terrestrial Invertebrate</td>
<td>4.93</td>
<td>29</td>
<td>29</td>
<td>Zungaro zungaro</td>
<td>-6.68</td>
<td>-6.86</td>
</tr>
<tr>
<td>6</td>
<td>Aquatical Invertebrate</td>
<td>25.68</td>
<td>30</td>
<td>30</td>
<td>Hoplosternum littorale</td>
<td>-41.04</td>
<td>-41.19</td>
</tr>
<tr>
<td>7</td>
<td>Cladocera</td>
<td>171.02</td>
<td>31</td>
<td>31</td>
<td>Astronotus crassipinnis</td>
<td>0.11</td>
<td>-0.1</td>
</tr>
<tr>
<td>8</td>
<td>Copepoda</td>
<td>-64.45</td>
<td>32</td>
<td>32</td>
<td>Pteropygichthys spp</td>
<td>-30.98</td>
<td>-31.18</td>
</tr>
<tr>
<td>9</td>
<td>Rotifer</td>
<td>36.85</td>
<td>33</td>
<td>33</td>
<td>Triportheus auritus</td>
<td>-14.81</td>
<td>-15.04</td>
</tr>
<tr>
<td>10</td>
<td>Protozoa</td>
<td>-9.49</td>
<td>34</td>
<td>34</td>
<td>Colossoma macropomum</td>
<td>15.48</td>
<td>15.21</td>
</tr>
<tr>
<td>11</td>
<td>Caymans</td>
<td>-26.77</td>
<td>35</td>
<td>35</td>
<td>Arapaima gigas</td>
<td>-17.84</td>
<td>-17.99</td>
</tr>
<tr>
<td>12</td>
<td>Dolphins</td>
<td>-7.7</td>
<td>36</td>
<td>36</td>
<td>Calophysus macropterus</td>
<td>-6.4</td>
<td>-6.65</td>
</tr>
<tr>
<td>13</td>
<td>Turtles</td>
<td>-40.85</td>
<td>37</td>
<td>37</td>
<td>Brachyplatystoma vaillantii</td>
<td>-13.64</td>
<td>-13.85</td>
</tr>
<tr>
<td>14</td>
<td>Waterfowl</td>
<td>-16.46</td>
<td>38</td>
<td>38</td>
<td>Triportheus sp</td>
<td>-30.15</td>
<td>-30.35</td>
</tr>
<tr>
<td>15</td>
<td>Otters</td>
<td>-65.21</td>
<td>39</td>
<td>39</td>
<td>Hypophthalmus sp</td>
<td>-51.51</td>
<td>-51.6</td>
</tr>
<tr>
<td>16</td>
<td>Otters</td>
<td>-63.03</td>
<td>40</td>
<td>40</td>
<td>Pinirampus pinirampu</td>
<td>-23.83</td>
<td>-24.01</td>
</tr>
<tr>
<td>18</td>
<td>Prochilodus nigricans</td>
<td>-50.79</td>
<td>42</td>
<td>42</td>
<td>Other Carnivores</td>
<td>29.14</td>
<td>29.14</td>
</tr>
<tr>
<td>19</td>
<td>Brycon amazonicus</td>
<td>8.73</td>
<td>43</td>
<td>43</td>
<td>Other Detritivores</td>
<td>-71.67</td>
<td>-71.71</td>
</tr>
<tr>
<td>20</td>
<td>Brachyplatystoma rousseauxii</td>
<td>-16.85</td>
<td>44</td>
<td>44</td>
<td>Other Insectivores</td>
<td>-36.74</td>
<td>-36.86</td>
</tr>
<tr>
<td>21</td>
<td>Brachyplatystoma filamentosum</td>
<td>-16.21</td>
<td>45</td>
<td>45</td>
<td>Other Omnivores</td>
<td>-4.27</td>
<td>-4.44</td>
</tr>
<tr>
<td>22</td>
<td>Semaprochilodus insignis</td>
<td>-61.37</td>
<td>46</td>
<td>46</td>
<td>Other Piscivores</td>
<td>-41.41</td>
<td>-41.51</td>
</tr>
<tr>
<td>23</td>
<td>Pseudoplatystoma punctifer</td>
<td>-15.67</td>
<td>47</td>
<td>47</td>
<td>Other Herbivores</td>
<td>-70.84</td>
<td>-70.91</td>
</tr>
<tr>
<td>24</td>
<td>Total catch</td>
<td>-27.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ACKNOWLEDGEMENTS**

The first author wishes to thank CAPES (Research Brazilian Agency) for granting the scholarship.

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ABSTRACT

The implementation of the European Water Framework Directive (WFD) has lead to the development of various biotic indices in order to assess the ecological status of aquatic ecosystems. These indices are mainly based on the structure of ecological communities (De Jonge et al., 2006; Hering et al., 2010). The main underlying assumption of such an approach is that structural features of selected ecological communities are representative of the ecological functioning of the ecosystem. In particular, the ecological status of transitional waters has to be assessed using fish-based indicators (FI) which is computed using observation data on species diversity and abundance.

Concurrently, stability, maturity and resilience features of ecosystems are often discussed using indices provided by Ecological Network Analysis (ENA). ENA is not only based on structural elements of ecological communities but also on a functional description of the ecosystem centred on energy flows.
The purpose of the paper is to discuss results of both approaches applied on 6 French estuarine areas (Figure 1). Values of French WFD indice (Delpech et al., 2010) are compared with Relative Ascendency (A/C), Internal Ascendency (Ai/Ci), Connectance Index (CI), Finn’s cycling index (FCI) and System Omnivory Index (OI) computed using estimates from Ecopath models. In a second time, attention is paid to sensitivity of ENA indices values to input data by considering resampling into confidence intervals of input data based on pedigree indexes.

Results (Figure 2) shows that values of CI, A/C and Ai/Ci seem consistent with FI values. These results contribute to the Biodiversity - Ecological functioning (BDEF) debate relating low structural diversity to high ecosystem activity which gave birth to a particularly intense controversy over the past fifteen years (see for instance Loreau et al., 2001; Loreau et al., 2002; Hillebrand & Matthiessen, 2009). These questions about the impact of perturbations on estuarine ecosystem suggest that Stress is correlated with low structural diversity/abundance which is here related to low food web organization and high (cycling) activity. Such as cycling activity could then be seen as a mechanism of resilience as suggested by several authors.

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REFERENCES


ANALYZING THE ECOLOGICAL ROLE OF FALKLAND SPRAT (SPRATTUS FUEGUENSIS) IN THE INNER SEA OF SOUTHERN CHILE

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ABSTRACT

The Falkland sprat (Sprattus fueguensis) is a small pelagic fish distributed in the south cone of South America. Whitehead (1985) indicated that S. fueguensis was distributed only in the southern Atlantic Coast of South America. However, in 2005 S. fueguensis was identified in the landings of a small-scale fishery operating in the inner sea of Southern Chile (Aranis et al., 2007). Before 2005, S. fueguensis was misreported in the catch as common sardine (Strangomera bentincki). After correcting the statistics it was clear that S. fueguensis is the most important pelagic resource in this area. From 2006 to 2013, S. fueguensis sustained >30 thousand tonnes per year, which represented >50% of total landings. Consequently scientists, managers and users have been focusing efforts to improve the knowledge on the biology and ecology of this species in southern Chile. Globally, small pelagic fish are low trophic level fisheries i.e., species that are located at low trophic levels that sustain important fisheries but also are food source for other fish species and other components of the food web such marine birds and mammals. Therefore, low trophic level fisheries such S. fueguensis are key in supporting ecosystem structure and function as well as food security. Since 2012, the Chilean Fisheries and Aquaculture Law considers conservation and sustainability as overall management objectives that must be accomplish considering the precautionary and ecosystem approaches to fisheries. Therefore, in this paper we present results from a research project funded by the Chilean Research Fund to study the ecological role of S. fueguensis in the inner sea of southern Chile (Neira et al., 2014).

We analyse S. fueguensis as prey and predator, carrying out diet composition analysis (stomach contents and isotopes) for S. fueguensis and its main prey and predators. These data as well as other input parameters such biomass, production/biomass ratios, consumption/biomass ratios, and catches were combined in a food web model using the Ecopath with Ecosim software (www.ecopath.org). The model considers 18 functional groups from primary producers and detritus to top predators. The emphasis, however, is in the trophic interactions of S. fueguensis and its main prey (e.g., zooplankton) and predators (e.g., southern hake, hoki, kingklip, and top predators). We evaluate flows and trophic interactions using network analysis contained in EwE. Later we fit the model to time series (2005-2012) of relative abundance for S. fueguensis using fishing mortality as forcing, in order to obtain plausible values for vulnerability parameters. Later, we perform simulations by affecting the biomass of S. fueguensis under several fishing mortality levels evaluating i) the effects of these changes in the biomass of prey and predators in the system, and ii) the current single-species reference points for S. fueguensis.

Regarding the ecological role in the system, S. fueguensis can be characterized as a small pelagic fish with a slightly higher trophic level compared to other small pelagic from the Humboldt Current System, due to its predation mostly on zooplankton (copepods and euphausiids). On the other hand, S. fueguensis is an important prey for consumers in the ecosystem i.e., fish, birds and mammals. The EwE model indicated that a decline in the biomass of S. fueguensis results in a decline in the biomass of predators such southern hake and kingklip, but also impacts (indirect effects) other groups such hoki and other pelagic fish, that benefit from a decline in predators biomass. The proxy used for management, i.e., that the maximum sustainable yield could be reached at 60% of the unexploited spawning biomass seems aggressive considering the dynamics of S. fueguensis and its trophic interactions.

---

We conclude that *S. fueguensis* plays a key ecological role as predator of zooplankton and prey for other fishery resources and, therefore, special considerations are needed for its sustainable exploitation. In particular, current reference points may not be as precautionary as needed, and therefore the sustainability of this fishery and others that target predators of this species may be at risk.

**ACKNOWLEDGEMENTS**

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MODELLING THE MEDITERRANEAN MARINE ECOSYSTEM AS A WHOLE: ADDRESSING THE CHALLENGE OF COMPLEXITY

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ABSTRACT

EwE models have been widely used in aquatic ecosystems to describe the structure and functioning of marine ecosystems, evaluate the impact of anthropogenic activities and environmental changes and explore fishing management policy options (Coll et al., 2009; Heymans et al., 2012). Here we applied the EwE approach to describe and assess the Mediterranean marine ecosystem structure and functioning as a whole. In particular, two food web models for the 1950s and 2000s periods were built to investigate: 1) the main structural and functional characteristics of the Mediterranean food-web during these time periods; 2) the key species/functional groups and interactions; 3) the role of fisheries and its impact; and 4) the ecosystem properties of the Mediterranean Sea in comparison with other European Regional Seas. Both models included about 100 functional groups and 7 types of fishing fleets and were divided it in 4 sub-models following the four sub-regions division given by the Marine Strategy Framework Directive (MSFD; 2008/56/EC): 1) Western Mediterranean Sea (W); 2) Adriatic Sea (A); 3) Ionian and Central Mediterranean Sea (I); 4) Aegean and Levantine Sea (E) to account for differences in environmental and biological characteristics (Piroddi et al., Submitted).

Results show that among all functional groups the highest trophic levels were observed for marine mammals and large predatory fish. The ecosystem flows were mainly dominated by lower trophic level organisms, as benthic invertebrates, zooplankton and phytoplankton while small pelagic fish, mainly European sardines and anchovies, prevailed in terms of biomasses and catches. Large pelagic fish, sharks and medium pelagic fish seemed to play a key role in the past ecosystem, replaced in more recent year by large pelagic fish, benthopelagic and benthic cephalopods. Fisheries showed large impacts on most living groups of the ecosystem in both time periods. Also, when comparing the Mediterranean to the other European Regional Seas, the Mediterranean stood alone in relation to the type of flows driving the system and the cycling indices, suggesting higher levels of community stress induced by intensive fishing activities. This study is the first that sets the basis to understand and quantify the entire Mediterranean Sea ecosystem including main marine organisms, from low to high trophic levels, and considering the fishing activity. The construction of two food web models (for the past and for current years) enabled us to...
Scientific advice for management

assess changes in the food web and impacts (in this case fishing) affecting the system. However, further developments of spatial and temporal dynamic simulations to both hind cast and forecast ecosystem dynamics are necessary to evaluate the exploitation status of the Mediterranean Sea and explore different management policies and future scenarios.

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MODELLING IMPACTS OF FISHING ON TROPHIC ENERGY FLOW IN MERSIN BAY, NORTH-EASTERN MEDITERRANEAN

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ABSTRACT

A mass-balance food web model was developed to identify its structure and impacts of fishing on the Mersin Bay ecosystem on the eastern Mediterranean coasts of Turkey.

The continental shelf of the Bay is relatively wide, even though most of the north-eastern Mediterranean is narrow. This bay is very productive for demersal fish and crustacean species due to having large continental shelf, bottom type and river discharge. Thus, the bottom trawl fishing fleet, which is 30% of the Turkish trawl fleet, are located in the area. Due to high biodiversity and the multi-species nature of the fishery, fisheries management is complicated. The major problems are overfishing and bycatch/discard issue. This area is also important for the lessepsian species migration (i.e. migration from the Red Sea to the Mediterranean via the Suez Canal), some of which have long been commercially exploited. These features were taken into account in this first Ecopath model of eastern Mediterranean coasts of Turkey, to test the impacts of fishing on the ecosystem.

The model was built for the period September 2009 to April 2013. 45 functional groups were defined by emphasizing on commercial and lessepsian species, including 1 group of primary producer, 9 groups of invertebrates, 2 groups of lessepsian invertebrates, 13 groups of demersal fish, 5 groups of demersal lessepsian fish, 7 groups of pelagic fish, 1 group of pelagic lessepsian fish, 2 groups of Chondrichthyes, 1 group of marine turtle, seabird, cetaceans, detritus and discard respectively. Input data was obtained from scientific surveys and commercial bottom trawl data. The data described detailed catch and discard compositions for each species. Discard in terms of weight was 47.6% and 52.4% was landed. Round sardinella was the dominant pelagic small fish in terms of biomass and red mullet, swimming crab (lessepsian), green tiger prawn, common cuttlefish, horse mackerel, ponyfish (lessepsian), brushtooth lizardfish (lessepsian) were the dominant demersal fish species respectively in terms of biomass and catch.

This model provides the necessary knowledge and baseline that will help to prevent the degradation of the Mersin Bay marine environment and will ensure sustainable utilization of fisheries-related goods and services provided by our marine ecosystem as an alternative approach to single species models.
MODELLING THE ECOSYSTEM UPTAKE AND TRANSFER OF SELLAFIELD-DERIVED RADIOCARBON (14C) IN THE MARINE ENVIRONMENT56

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ABSTRACT

The nuclear energy industry produces radioactive waste at various stages of the fuel cycle. In the United Kingdom, spent fuel is reprocessed at the Sellafield facility in Cumbria on the North West coast of England. Waste generated at the site comprises a wide range of radionuclides including radiocarbon (14C) which, due to its long half-life (5730 years), environmental mobility and high bio-availability, is the largest contributor to collective dose commitment from the entire nuclear industry (BNFL 2002). 14C is disposed of in various forms, one of which is as highly soluble bicarbonate (H14CO3-) within the low level liquid radioactive effluent, via a pipeline, into the Irish Sea. Previous research has shown that 14C activity in intertidal organisms and mollusc shells have increased due to Sellafield discharges (Cook et al., 2004; Muir et al. 2014). 14C is able to enter the marine food chain through uptake by primary producers. As energy is transferred through the food chain 14C is subject to trophic transfer and bio-accumulation.

Due to a net northerly flow, 14C is dispersed not only within the semi-enclosed Irish Sea but also northwards through the North Channel and around the Scottish west coast. This study considers the near-field bioaccumulation of 14C within the Irish Sea, the northward transport mechanisms and subsequent ecosystem uptake in waters off the Scottish west coast. 14C concentrations will be measured in surface water carbon fractions (particulate inorganic/organic carbon and dissolved inorganic/organic carbon) and in marine (inorganic/organic) and intertidal (inorganic) sediments. An integrated food web study is currently being conducted to investigate 14C bioaccumulation by analysing various marine species at different trophic levels. The data gathered is being used to parameterise Ecopath with Ecosim models of the area, tracing bioaccumulation of radiocarbon by using Ecotracer.

ACKNOWLEDGEMENTS

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Scientific advice for management

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A TROPHIC MODEL FOR MAMANGUAPE MANGROVE ESTUARY (NORTHEASTERN BRAZIL) CONFIRMS THE PROMINENCE OF DETRITUS ROLE

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ABSTRACT

The Mamanguape Estuary is the second largest in Paraíba State (Brazil). It is inserted in an Environmental Protected Area (EPA), which encompasses 14,640 hectares of preserved mangroves, Atlantic Forest remainders, various estuarine biotopes and a fringe rocky reef formation (Xavier et al., 2012). The natural environment is associated with human villages, including indigenous people that use sea resources, such as mangrove wood and fisheries (Paludo & Klonowski, 1999). In order to assess information on dynamics of the main species, we describe the food web and developmental stage of Mamanguape Estuary System by creating a trophic steady state model, using the Ecopath with Ecosim Software (EwE).

The model has 24 compartments: three primary producers (phytoplankton, mangroves and macroalgae), twenty consumers compartments (including zooplankton, zoobenthos, shrimps, crabs, fishes and manatees) and also a detritus compartment. Biomass of phytoplankton, macroalgae, zoobenthos, macrocrustaceans and fish groups were obtained by field sampling, as well as fish diet composition by stomach content analysis. Local Fisheries were estimated by interviews with local residents. All samplings were performed between November/2011 to November/2012. Others EwE parameters (PB, QB, EE) were obtained from empirical regressions and similar studies and/or models.

Figure 1. The Mamanguape Estuary System flow diagram organized by its integer trophic levels (TL) in the form of the Lindeman spine.
Results showed that the food web was dominated by a detritus pathway (Figure 1), since detritivory predominates over herbivory (D/H ratio of 2.03). The ecosystem flow statistics, total primary production/total respiration, Finn’s cycling index and ascendancy were 1.23, 24.8%, and 30.8%, respectively, indicating that the Mamanguape Estuary is a highly resilient system, with properties close to maturity, according to Odum’s theory of ecosystem development. These parameters and many others are presented in Table 1, in comparison with others estuarine systems in American Continent.

When estuarine and reef zones were analyzed as isolated models, major differences were related to the mangrove presence in the estuarine zone, but flow statistics pointed basically to the same resilient and maturity stage. Mangroves seem to play an important role as a detritus supplier for both zones, as well as the rocky reef barrier functions by retaining detritus from the river discharge. In order to preserve the study area properties of high production, maturity and resilience, policy decisions should be made to prevent conflicts over the use of natural resources in the area.

Table 1. Ecosystem attributes based on the Mamanguape Estuary trophic model and comparison with other estuarine systems in America: Caeté Estuary, Brazil; Gulf of Nicoya, Costa Rica; and Celestun Lagoon, Mexico.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mamanguape Estuary, Brazil</th>
<th>Caeté Estuary, Brazil</th>
<th>Gulf of Nicoya, Costa Rica</th>
<th>Celestun Lagoon, Mexico</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOURCE</td>
<td>Present study</td>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>STATISTICS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum of all consumption</td>
<td>3179.8</td>
<td>3746.7</td>
<td>1161.0</td>
<td>1931.0</td>
</tr>
<tr>
<td>Sum of all exports</td>
<td>394.5</td>
<td>2185.8</td>
<td>485.5</td>
<td>14510.0</td>
</tr>
<tr>
<td>Sum of all respiratory flows</td>
<td>1732.2</td>
<td>948.2</td>
<td>676.5</td>
<td>1040.0</td>
</tr>
<tr>
<td>Sum of all flows into detritus</td>
<td>2288.6</td>
<td>3678.0</td>
<td>726.3</td>
<td>1609.0</td>
</tr>
<tr>
<td>Total system throughput</td>
<td>7764.9</td>
<td>10558.6</td>
<td>3049.3</td>
<td>4581.0</td>
</tr>
<tr>
<td>Sum of all production</td>
<td>2806.1</td>
<td>3555.1</td>
<td>1414.3</td>
<td>16536.0</td>
</tr>
<tr>
<td>Mean trophic level of the catch</td>
<td>1.18 (2.42*)</td>
<td>2.08 (3.1*)</td>
<td>4.06</td>
<td>3.57</td>
</tr>
<tr>
<td>Gross Efficiency (catch/net p.p.)</td>
<td>0.003</td>
<td>8.6</td>
<td>0.003</td>
<td>0.00001</td>
</tr>
<tr>
<td>Calculated total net primary production</td>
<td>2126.8</td>
<td>3134.4</td>
<td>1162.0</td>
<td>15550.0</td>
</tr>
<tr>
<td>Total primary production/total respiration</td>
<td>1.228</td>
<td>3.305</td>
<td>1.720</td>
<td>15.900</td>
</tr>
<tr>
<td>Total primary production/totai biomass</td>
<td>0.503</td>
<td>0.239</td>
<td>11.6</td>
<td>64.0</td>
</tr>
<tr>
<td>Total biomass/total throughput</td>
<td>0.557</td>
<td>1.244</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>Total biomass (excluding detritus)</td>
<td>4227.1</td>
<td>13132.2</td>
<td>132.1</td>
<td>258.56</td>
</tr>
<tr>
<td>Total catch</td>
<td>7.42 (0.75*)</td>
<td>2683.183 (18.3*)</td>
<td>3.38</td>
<td>0.26</td>
</tr>
<tr>
<td>Connectance Index</td>
<td>0.26</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>System Omnivory Index</td>
<td>0.13</td>
<td>0.11</td>
<td>-</td>
<td>0.20</td>
</tr>
<tr>
<td>Detritivory/Herbivory (D/H)</td>
<td>2.03</td>
<td>1.17</td>
<td>1.11</td>
<td>2.00</td>
</tr>
<tr>
<td>ASCENDENCY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Ascendência (%)</td>
<td>30.8</td>
<td></td>
<td>26.1</td>
<td>24.7</td>
</tr>
<tr>
<td>Total Overhead (%)</td>
<td>68.9</td>
<td>69.6</td>
<td>73.9</td>
<td>75.3</td>
</tr>
<tr>
<td>CYCLES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finn’s cycling index (%)</td>
<td>24.8</td>
<td>17.9</td>
<td>5.5</td>
<td>13.4</td>
</tr>
<tr>
<td>Finn’s mean path length</td>
<td>3.571</td>
<td>3.4</td>
<td>-</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Sources citation: (a) Wolff et al. (2000); (b) Wolff et al. (1998); (c) Vega-Cendejas & Arreguín-Sanchez (2001). Asterisks (*) indicates parameters values without mangrove harvest.

ACKNOWLEDGEMENTS

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ABSTRACT
The need to consider changes in natural resources as well as human activities when analysing and managing marine ecosystems highlights the necessity to adopt an integrated view. Since the productivity of marine resources depends on the ecological state of communities and ecosystems, and on external drivers, not only the dynamics of target species, but also the dynamics of non-target organisms, trophic relationships and energy flows, environmental factors and human impacts have to be considered to manage our seas properly. In the last decade, the scientific community made substantial progress in the identification and quantification of multiple human threats that impact marine diversity, habitats, and ecosystems. Currently, there is increasing knowledge on the identification and quantification of these multiple drivers. However, the way these drivers may interact and combine to impact productivity patterns of marine ecosystems is not well known. Multiple drivers may interact and their effects may cause impacts that accumulate in an additive way or may act synergistically or antagonistically at different ecological levels. A comprehensive understanding of these impacts and their interactions is mostly lacking. In addition, multiple impacts are distributed in a heterogeneous way spatially and temporally, and their interactions do not occur the same way everywhere, affecting productivity differently. Moreover, future changes of current human activities (such as climate change, fishing or the invasion of new species), and the appearance and spread of new activities (such as deep sea exploitation), will likely challenge our current understanding. To tackle some of these scientific challenges there is a growing need to develop and use novel methodologies of data integration, assimilation and modelling at different scales, taking into account uncertainties in data and processes. Here we provide an overview of the challenges the scientific community is currently facing to model these cumulative dynamics, on the progress achieved in the last decade and on how novel modelling approaches within the Ecopath with Ecosim approach can contribute to this progress.

ECOPATH MODELLING OF A SUBARCTIC NORWEGIAN FJORD AFTER A DECLINE IN THE COASTAL COD (GADUS MORHUA) STOCK AND INVASION OF RED KING CRAB (PARALITHODES CAMTSCHATICUS)

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ABSTRACT

Atlantic coastal cod has historically been a dominant top-predator and the main target for fishery in the subarctic Porsangerfjord (area 1800 km²) in northern Norway. In Porsangerfjord, the environment changes from warmer atlantic conditions with bottom temperature of ca. 2–5°C in the outer part of the fjord (area 1 in Fig. 1) to arctic conditions in the inner part of the fjord (areas 4W and 4E) with bottom temperatures around 0°C. The former cod-dominated Porsangerfjord ecosystem has changed after a period of low cod recruitment and a severe decline in cod stock biomass after the mid 1990’ies. Sea urchins (Strongylocentrotus droebachiensis) have grazed down much of the former macroalgae covered cod nursery areas in the middle and inner part of the fjord. The invasive red king crab (Paralithodes camtschaticus) has increased dramatically since 2006 and it has now become a new dominant benthic top predator in the fjord. The main objective of this study was to investigate major patterns in the food-web structure after the decline in the coastal cod stock, and how these patterns varied along the fjord.

Pelagic and benthic invertebrates, fish and other top-predators were sampled during 2008-2011. Fish and shrimp were sampled by research bottom trawl during each quarter on at least two locations in each sub-area (Fig. 1). Benthic invertebrates were sampled by grab (infauna) and epibenthic sledge (larger epifauna). Abundance of sea mammals and birds were estimated by sighting surveys. Ecopath mass-

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balance food web models were built in order to evaluate how groups interact with cod and thus identify the potential mechanisms preventing recovery of the cod stock. Since the sub-areas in the fjord are considerably different in environmental and biological conditions, Ecopath models were made for the five sub-areas of the fjord, for the time period 2008-2010. Each model comprised 62 ecological groups (Fig. 2).

Cod abundance was highest in the outer area 1, decreased in area 2 and 3, and in the innermost areas 4E and 4W, almost no cod was caught. The trawl CPUE of deep-water shrimps, capelin and herring had an opposite trend with very high CPUE in the inner and colder area 4E and 4W and much lower CPUE in the outer areas. On a trawl-haul basis, deep-water shrimp CPUE was negatively correlated to cod CPUE indicating that lack of predation from cod contributed to high shrimp biomass especially in area 4E. It is known that cod was abundant in the eastern inner colder area 4E prior to the cod stock decline.

The Ecopath models for area 1-3 indicate that cod was the main predator on small deep-water shrimp, capelin and herring and also on small cod through cannibalism (Fig. 2). After the decline in the cod stock, the distribution range of the cod stock has decreased to the warmer outer areas 1-3, potentially resulting in high biomasses of shrimp, capelin and herring in the colder inner area 4, due to the lack of cod predation (top-down effect). Despite high individual growth rates of cod in recent years, cod recruitment has been low. High abundance of sea urchins at shallow water still maintains barren grounds in these former cod nursery grounds, and contributes to low cod recruitment and a “simplified” food-web, lacking cod in the inner colder area.

The red king crab firstly invaded the outer areas 1, 2 and 3 with highest abundance on the western side of the fjord. The red king crab has established as a major predator on benthic invertebrates but has until recently not been observed in the inner colder areas 4E and 4W. Biomass and production of benthic invertebrates were much higher in these colder areas than in the warmer areas further out. The red king crab also feeds on sea urchins and may hypothetically reduce sea urchin abundance and hence reduce their overgrazing of the macroalgae which form nursery areas for small juvenile cod. We conclude that the food-web structure of Porsangerfjord has changed dramatically due to the changes in stocks of cod, the red king crab, sea urchins and macroalgae.
Figure 2. Food-web based on an Ecopath model of area 3 in Porsangerfjord. Lines show trophic links between ecological groups. Size of groups symbols are scaled to group biomass. Red lines show the links between large cod (> 35 cm in length) to major prey groups. Links between macroalgae groups and their major grazer, the herbivore echinoids (sea-urchins) are shown in blue. Macroalgae covered bottom form nursery grounds for juvenile cod (< 25 cm in length).
ECOTROPHIC MODELING OF ANTHROPOGENIC CUMULATIVE IMPACTS ON THE SUSTAINABILITY OF FISHERIES PRODUCTIONS: COMPARISON OF LAKE ERIE AND GREAT SLAVE LAKE ECOSYSTEMS

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ABSTRACT

Human activities impact aquatic systems in a multitude of ways, yet the cumulative impacts of multiple anthropogenic stressors on ecological dynamics remain largely unknown. Historically, habitat loss and over-exploitation of key fish species were two of vital human impacts on landscapes. Recently, this list has grown to include pollution-hypoxia, non-indigenous species (NIS) invasion, and hydroclimate changes among many other stressors. All those stressors interacted together and accumulated, leading to our recognition of inability to probe into the underlying mechanisms by traditional simple or straightforward statistical methods. Instead, the complexity of lacustrine ecosystems necessitates a holistic approach; ecosystem-based modeling explicitly accounts for ecological interactions that can reveal unexpected indirect effects. Ecopath creates a novel pathway to integrate a wide spectrum of biological production components into an inter-connected roadmap through prey-predator arena. Combined these food-web productions with a set of vulnerability analysis, Ecosim can be applied for modeling of spatial and temporal responses of fisheries production dynamics to various cumulative impact scenarios. In this

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study, we integrated an array of multidisciplinary information to construct ecosystem-based biomass production models for Lake Erie and Great Slave Lake. The main objectives of this study were 1) to set up baseline conditions or ecological thresholds of both ecosystem changes, 2) to disclose how cumulative impacts affect the ecosystem resilience to anthropogenic disturbance under scenarios of one or multiple cumulative stressors exerted, and 3) to assess the sustainability of fisheries productions against the vulnerability if varying trophic states of the ecosystems.

Two great lake systems are involved for comparative assessment of the sustainability fisheries productions through ecotrophic modeling. Lake Erie is one of the smallest and shallowest, but most productive freshwater ecosystems to support important recreational and commercial fisheries in the Laurentian Great Lakes. Recent introductions and establishments of low-trophic NIS have resulted in a series of profound modifications in disrupting food web, instablizing fish community, and deteriorating physical environment. Great Slave Lake (GSL) is suited in the sub-polar Canada north, typically characterized as the second largest, the deepest, and oligotrophic McEnzie great lake. In connection with hydroclimatic water inflow through Slave River and drains into Mackenzie River system, GSL sustains the largest commercial, recreational and aboriginal (CRA) fisheries in Northwest Territories since the mid-1950s. In addition to the river-lake interaction, the environmental impacts are also linked to the exploration of mining resources around the lake. Emission, erosion and effluent of mining by-product, like Arsenic trioxide, and chemical compounds from underground storage cambers at the mine were washed and entered into aquatic ecosystem, finally arriving in human body through food web paths. Confronted with the reality of changing ecosystems and increasing anthropogenic impacts, comprehensive modeling approach has become a central to manage the impacted ecosystem in a sustainable framework. Using Ecosim, baseline models were constructed with a set of functional components ranging from detritus, diatom, zooplankton, benthos, fish, and waterfowl to delineate the food web structures and functional linkages for Lake Erie in 1999-2003 and Great Slave Lake 2011-2014. Historical data back to the 1970s were provided to the balanced models for model calibrations and vulnerability analyses, signifying the considerable differences of two ecosystem properties. Some functional groups (e.g. piscivore predators and demersal invertebrates) were predicted to respond favourably under cumulative effects in some regions. In Lake Erie, nutrient loading and NIS-based foraging arena functioned as strong bottom-up modification of food web. Fisheries for harvesting piscivore-dominated fishes, such as Walleye and Yellow Perch in Lake Erie, significantly control the importance of high trophic-level predators. In GSL, fisheries harvest is relatively limited, but the ecosystem functionality is significantly influenced by the capacity of adaptation and vulnerability of model components, particularly in the lower trophic groups. The overall ecosystem development largely depended on the balance between two-way anthropogenic impacts. Finally, a number of events or scientific questions-oriented scenarios were formulated to facilitate ecosystem simulations by Ecosim, addressing possible fisheries management options to the sustainability of fisheries populations. The model generated many hypotheses about relationships between key biota in both lakes’ food web and may ultimately provide important insights on the nature of the risks and opportunities posed by NIS, exploitation and hydroclimate changes in the aquatic systems, highlighting opportunities for policy response and providing insights on how to conduct cumulative impact research in a comparative framework.

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We acknowledge many people, who dedicated to collecting, organizing and maintaining long-term monitoring information on several functional components of both studied lakes, in particular members of Lake Erie Committee. During the study, Andy Cook, Jeff Tyson, Jim Markham, Chuck Murray, Martin Stapanian, Megan Belore, Don Einhouse, Jan Ciborowski, Ron Dermott, Ora Johannsson, Joe Makarenwicz, Marten Koops, Villy Christensen, Craig Hebert, George Low, Vicki Lee, Robert Sutherland, offer their wisdom, knowledge, and experience. Their constructive discussion, contribution of original and published literature sources, and knowledgeable comments have greatly benefited the possibility of this comprehensive analysis. We are also grateful to Canada-Ontario Agreement funding for a COA project “understanding the ecosystem changes”, to Ontario Ministry of Natural Resources and University of Windsor, Northwest Territories Cumulative Impact Monitoring Program (NWT-CIMP) and DFO Aboriginal Fisheries Strategies (AFS) continuously funded a research project “integrated ecomonitoring and assessment of cumulative impacts on Great Slave Lake fisheries ecosystem” since 2011.

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Modelling cumulative ecosystem dynamics


Evaluating the ecosystem effects of variation in recruitment and fishing effort in the western rock lobster fishery

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ABSTRACT

We used a regional, ecosystem mass-balance model (Ecopath with Ecosim) to evaluate the possible changes in flows of mass and energy between the benthic and pelagic components of the marine ecosystem of Jurien Bay in temperate Western Australia (~30° S, ~115° E). The effects of varying the biomass of western rock lobster in the system were examined by simulating changes in commercial and recreational fishing mortality as well as recruitment-driven changes in the abundance of lobster puerulus (the first post-larval stage). The model comprised 80 functional groups (more than 200 species). A simulated closure of the commercial lobster fishing was predicted to lead to an increase in lobster biomass of 160% after 20 years, with changes in biomass of up to 20% of the main prey and predators of lobster. Since 2006/07, the puerulus settlement (recruitment to the benthos) of western rock lobster has declined to the lowest levels recorded in the fishery. The model predicted that under 2005 levels of fishing effort, a simulated depletion of 90% of puerulus biomass resulted in an ~17% reduction in the biomass of adult lobster biomass after 20 years (i.e. by 2025). In general, the model predicts that the variations in lobster biomass, whether induced from fishing mortality or declining puerulus settlement, have relatively small effects on the biomass of the main predators and prey of lobster in the marine park. The relative biomass of adult rock lobster and their associated predators and prey was more sensitive to fishing than to variations in recruitment.

Comparative ecological analysis of Mediterranean deep-sea ecosystems and simulations of global change

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Abstract

Deep-sea ecosystems need allochthonous energy for their functioning. Continuous sinking streams of particles and occasional, still unpredictable, point-like pulses of organic matter are the processes performing the required energy input. Productivity of the benthos is related with food availability or, more specifically, to marine snow input. Thus, as ocean waters have undergone a constant warming over the past century, the levels of primary productivity (and, by consequence, the marine snow input) have been observed to fluctuate with different patterns across the oceans.

Mediterranean deep-water masses have undergone a warming trend in the past decades, a process which might be ascribed to local climate change. Furthermore, the higher temperatures of the Mediterranean intermediate and deep waters (13–14 °C), compared to the Atlantic Ocean, enhance the degradation of organic matter by prokaryotic metabolism. Future warming will thus amplify the reduction of food availability from the deep seafloor ecosystems, whose effects have rarely been studied until now.

An ecosystem model of the deep western Mediterranean Sea was recently developed representing the Catalan continental margin at mid-lower continental slope depths (Tecchio et al. 2013), using the Ecopath with Ecosim (EwE) approach and software (Christensen and Walters 2004). Here, we expanded the study to capture the longitudinal extension of the Mediterranean Sea. Thus, two additional models were set up for the central deep basin (western Ionian Sea) and the eastern basin (southern Cretan Sea), using data from a trans-Mediterranean sampling cruise conducted in 2009 and following a similar procedure than for the western deep sea model. The 3 models included 17 living compartments (18 in the western basin due to the presence of Risso’s smooth-head, Alepocephalus rostratus) and 2 detritus groups (sediment detritus and marine snow). Organic matter input was provided by annual import of marine snow to the ecosystem.

Ecological network analyses were performed using the plugin included in the EwE package. Results showed that the total production, consumption, respiration, export, and flows to detritus decreased from west to east. The ratio between primary input and total biomass also decreased with latitude, indicating an increasing trophic limitation and competition for resources. System omnivory was low in the 3 models,

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and stable with latitude, indicating that all 3 deep-sea basins show a structure that is more chain-like than web-like.

The biomass trophic spectrum (Gascuel et al. 2005) evidenced a steep decline in transfer efficiencies between trophic levels from the western basin to the eastern basin (Figure 1). The majority of biomass was concentrated over TL of 2.5–3.5, if we exclude the peak at TL 1 produced by detritus. The contribution of higher trophic levels to the total biomass was lower in the central and eastern basins, suggesting an increase of importance of mid-web functioning as the food availability decreases. The decline in transfer efficiency was also evident along the discrete trophic chain.

Temporal simulations of increase and decrease of marine snow (POC) input over 50 years, based on the results by Boyce et al. (2014), were then run for each model using the Ecosim temporal dynamic module. Results showed a direct relation between the simulated marine snow variation and the diversity of the ecosystem, estimated by Kempton’s Q index. For the Western basin model, we run simulations with and without an additional fishery scenario, described in Tecchio et al. (2013), which models the arrival of the red shrimp trawl fishery at 1000-1400 m depth. In the western basin, the fishery-driven impact was an order of magnitude larger than the productivity-driven impact. Fishery also positively impacted the proportion of invertebrate groups over fish groups, in terms of biomass, indicating an effect of community-composition shift.

Deep-water ecosystems of the eastern Mediterranean Sea, probably due to their reduced relative basal diversity and standing stock, can respond negatively to reductions in organic matter input, even without the man-driven impact of fisheries. On the other hand, based on the simulations on the western basin model, the interaction between climate effects and trawl fisheries was not observed, confirming the latter as the strongest shaper of benthic communities on human temporal scales.

ACKNOWLEDGEMENTS

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MARINE FOOD WEBS AND WARMING SCENARIOS: MODELLING A THERMOPHILIC SPECIES INVASION

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ABSTRACT

Within a context of climate changing, sea surface temperature has been raising in the last decades over most of the Globe, and it is predicted to raise further in the short as well as in the long term (IPCC, 2013). In particular, this general trend is expected to impact the Mediterranean Sea (Somot et al., 2008). Here, like in many other major basins, a northward shift of thermophilic alien species has already been observed (Zenetos et al., 2012), and is likely to keep going on in the future, impacting community structure and ecosystem functioning. In this scenario, the northern Adriatic Sea becomes an interesting case study to investigate the dynamics related to the combined action on the ecosystem of different drivers, such as the SST raise and the invasion of new species. Indeed, being characterised by a subatlantic climate, which allows for the presence of species typical of cold waters, and being a semi-enclosed basin which acts as a cul-de-sac preventing any further northward migration (Ben Rais Lasram et al., 2010), it configures as an ideal candidate to highlight the dynamics underlying such changes.

In this work, we discuss the sensitivity analysis and the results of an Ecopath with Ecosim model for the northern Adriatic Sea, built to explicitly take into account the arrival of alien thermophilic species and the effects of SST raise, in order to analyse the role of the different drivers in influencing the temporal evolution of the system, as well as to provide information which could be useful from a management point of view. The model is an update of the one proposed by Zucchetta et al. (2003), updated with 2007-2008 data. It has a mid-complexity structure, accounting for the main functional groups constituting the system, rather than the individual species. This allows to provide a synthetic representation of the ecosystem, without, reducing the capability to represent the main trophodynamic processes. To simulate the effect of the arrival of thermophilic species, dedicated functional groups, exclusively composed of alien species, were introduced in correspondence to the indigenous ones. The thermophilic groups were defined based on species already observed in the basin, and on those whose arrival is likely in the immediate future. Parameters for the new groups were calculated taking into account productivity and consumption rates of the invasive species, as well as the specific diets. The initial biomass for the invasive groups was set to very low values, so to represent a pre-invasion status. The final updated model thus consisted of 30 living functional groups, plus 2 detritus groups and 5 commercial fishing fleets. To perform dynamic simulations with increased SST scenarios, the effect of temperature (T) has been specifically introduced by using an external function acting on the search rates of each functional group. In this way, by acting directly on T, it

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was possible to test the effects on ecosystem functioning and structure induced by an increase of SST. The relation used to link the search rates to temperature was the one introduced by Lassiter and Kearns (1974) and defined through three parameters: the optimum temperature (Topt) for which the search rate is maximum, the maximum temperature (Tmax) above which the search rate is null, and a parameter c which accounts for the sensitivity of a population to temperature variations. The parameters for each group were estimated based on the latitudinal distributions of the species composing them.

Simulations were performed to test both the sensitivity of the model outputs to i) expected temperature increase and to ii) the parameters of the function linking temperature and search rates. In the first case, 30 years-long simulations were repeated 20 times, applying, for the first 10 years, a linear increment of the annual mean SST from the value recorded in 2007 (18.4°C) to a final temperature ranging from 19.2°C to 19.6°C. For the remaining 20 years the temperature was maintained constant, to stabilise the system. In the second case, 100 simulations were conducted, each considering different combinations of Topt, Tmax and c for every single group. Each value was randomly extracted from a normal distribution centred on the actual estimated parameter. Simulations were performed also in this case over 30 years, applying a linear temperature raise from 18.4 to 19.4°C for the first 10 years. Moreover, a set of simulations was performed based on the SST raise projections for the northern Adriatic Sea by Somot et al. (2006), considering the IPCC A2 scenario. These implied a 0.03°C raise per year, and thus the forcing was applied for 30 years to obtain a large enough temperature raise, and the results were taken at 50 years. To better understand the dynamics going on in the system, 4 different sets of simulations were performed: in the first one, the forcing was applied to every group in the system, in the second one it was applied only to local groups, in the third one a noise component was added to the forcing, to account for a random annual variability, and in the fourth one an initial phase of adaptation to the temperature raise was introduced for the local groups. For each set of simulations, three different primary production scenarios were tested: no change in PP, an exponential increase in production due to temperature, and a linear decrease of 20% in 30 years representing the actual oligotrophication trend detected in the basin (Giani et al., 2012).

Results of the sensitivity tests highlighted the existence of nonlinear effects in the food-web, so that simulation results can’t be directly deduced from the starting conditions. The influence of the temperature-forcing parameters was shown to be significant, mainly affecting negatively native groups at the middle-high trophic levels. Moreover, the MTI analysis allowed to discriminate groups more impacted by the temperature driver from those more influenced by the trophic effects. Simulations based on realistic SST raise scenarios showed, as expected, a general positive effect on the relative biomass of the invasive thermophilic groups. On the other hand the results for native groups, as well as for fisheries, showed a very complex pattern, with some groups suffering extremely negative impacts, while others were less affected and some showed a biomass gain. The effects on the invasive groups didn’t change much when applying the temperature forcing to native groups only, suggesting that invasive species may benefit more from the reduced competition rather than from more favourable climatic conditions. The system proved to be only slightly affected by annual variability, while introducing an adaptation phase to temperature change for native groups reduced the intensity of the effects on all groups. In all cases, PP increase produced a positive effect in term of biomass on the whole system, while PP decrease impacted negatively on all groups.

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Modelling cumulative ecosystem dynamics


REPRESENTING VARIABLE HABITAT QUALITY IN A SPATIAL FOOD WEB MODEL

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ABSTRACT
Why are marine species where they are? The scientific community is faced with an urgent need to understand aquatic ecosystem dynamics in the context of global change. This requires development of scientific tools with the capability to predict how biodiversity, natural resources, and ecosystem services will change in response to stressors such as climate change and further expansion of fishing.

Species distribution models and ecosystem models are two methodologies that are being developed to further this understanding. To date, these methodologies offer limited capabilities to work jointly to produce integrated assessments that take both food web dynamics and spatial-temporal environmental variability into account.

In order to bridge the gap between ecosystem models and species distribution models we have extended Ecospace, the spatial-temporal explicit module of the Ecopath with Ecosim (EwE) modeling approach (Walters et al., 1999; Walters et al., 2010), with the means to include the impacts of variable habitat quality on modelled spatial population distributions.

The original Ecospace model has been limited in the way habitat is represented as a fixed parameter in the spatial model, providing limited support to represent changes in the quality and extent of habitats. Large-scale habitat structures with associated impact on biomass distributions and trophic interactions have been represented only by a binary habitat use pattern, with each spatial cell being either entirely suitable -
or entirely unsuitable - for species/functional groups. The original Ecospace model thus assumed homogenous conditions within each spatial cell, and local, but possibly relevant variations within cells, could not be represented. This binary formulation has been particularly troublesome for models representing ecosystems where there is strong ‘sub-grid’ spatial structure of one or more key habitat types, e.g., small but productive reef structures that are smaller than a single grid cell, or strong, productive, and significant coastal structures that cannot be represented as entire cells.

The new habitat capacity model (Christensen et al., Under review) offers the ability to drive foraging capacity of species from the cumulative impacts of multiple physical, oceanographic, and environmental factors such as depth, bottom type, temperature, salinity, oxygen concentrations, etc. (Figure 1), which have cumulative impacts on the ability of functional groups to forage. The change is fairly simple and mainly implies to replace a binary habitat variable with a continuous habitat suitability factor, where the area that species can feed in each cell is determined by functional responses to multiple environmental factors. This modification builds on the fact that animal populations have lower local impacts as the size of their forage area increases. Since cell capacity is calculated for every functional group at every time step, this modification makes the model fully temporal and spatially dynamic.

This development bridges the gap between envelope environmental models and classic ecosystem food-web models, progressing towards the ability to predict changes in marine ecosystems under scenarios of global change and explicitly taking food-web direct and indirect interactions into account. As a next step, we also intend to explore the functioning of the habitat capacity model when driven by spatial-temporal variations in environmental conditions as presented in Steenbeek and co-authors (Steenbeek et al., 2013).

**Figure 1.** Schematic diagram of the habitat capacity model calculations with four (hypothetical) environmental preference functions (any number of functions is possible). During model run, cell-specific environmental parameter values can be read from data layers for each time step, and a cell-specific habitat capacity value is estimated as the product of the environmental preference values. No weighting is used, but weighting can be considered by altering the shapes of the environmental preference functions (Christensen et al., Under review).

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ADVANCES ON MODELLING SPATIAL-TEMPORAL ECOSYSTEM DYNAMICS IN THE MEDITERRANEAN SEA

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**ABSTRACT**

Marine ecosystems provide an essential contribution to human wellbeing in multiple ways and yet they are pressured by a diversified number of anthropogenic stressors which we know little about, particularly in relation to the ways threats affect marine species and ecosystems.

In this context, we used the new temporal and spatial module (Steenbeek et al., 2013) and the new habitat capacity model (Christensen et al., Submitted) of the Ecopath with Ecosim software, focusing on the...
Modelling cumulative ecosystem dynamics

Mediterranean Sea, to assess the cumulative impact of fishing activity and changes in environmental conditions (e.g., SST, salinity, primary production) on the whole ecosystem.

In particular the model, representing the year 1950s, consisted of about 100 functional groups and 7 types of fishing fleets and was divided in 4 sub-models following the four sub-regions division given by the Marine Strategy Framework Directive (MSFD; 2008/56/EC): 1) Western Mediterranean Sea (W); 2) Adriatic Sea (A); 3) Ionian and Central Mediterranean Sea (I); 4) Aegean and Levantine Sea (E) to account for differences in environmental and biological characteristics (Piroddi et al., Submitted).

The Ecopath model was first fitted to time series of observed data. Then, by using the habitat capacity framework (Figure 1), the model was run to evaluate species/functional groups distribution based on fishing impact and changes in the environment. The aim of the study was to quantify, using spatial and temporal dynamic simulations, ecosystem dynamics to assess the exploitation status of the Mediterranean Sea and explore different management policies and future scenarios. Quantifying the impact of important threats (e.g., climate change and fishing pressure) on a system that is defined 'under siege' (Coll et al., 2012) becomes critically important for ensuring the sustainability of marine resources and the services they provide to humans, and the conservation of this vulnerable ecosystem.

![Figure 1. Depth layer of the Mediterranean Ecopath model used for this study.](image)

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BIOCHEMICAL TRACER TECHNIQUES AND THEIR UTILIZATION IN ECOSYSTEM MODELS

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ABSTRACT

Despite considerable advances and management reliance, the ability of most ecosystem models to accurately quantify and project responses to fishing and environmental changes, is still limited by large uncertainties in the empirical data used to parameterise models and assess their performance. Furthermore, parameters that can change by orders of magnitude over various scales in time and space (diet, growth, life-history traits and behavioural responses), particularly under environmental or anthropogenic stress, require continued reassessment. Fundamental to most ecosystem models is a network budget analysis of energy, carbon or mass flow, which rely on thorough understanding of organic matter processing and predator-prey relationships. However, in ocean research, logistics multiply the cost constraints associated with undertaking traditional labour intensive methods such as stomach content analysis and recording biometrics.

Biochemical tracer techniques now provide an established and cost effective means to evaluate multiple biological processes that operate over different scales and interact with different physical and chemical processes (Young et al. 2014). Measurements of bulk stable nitrogen and carbon isotopes, lipid and fatty acids, trace elements and amino acids now routinely provide food web, growth, life-history and physiological data integrated over time and space (e.g., Post 2002, Parrish 2013, Bustamante et al. 1998). They are increasingly being used to define food web components (trophic positions and diet matrices), dominant basal food sources, and scalable measures for ascertaining ecosystem health. Used in combination, they hold great promise for better understanding mechanisms by which organisms respond to environmental change. Despite this, their utilisation in conjunction with ecosystem modelling has to date been limited.

In this study, we give an overview of how established biochemical tracer techniques and statistical models are being commonly applied in marine ecology (Table 1) and how they are currently, or could potentially assist in directly improving and evaluating the reliability of ecosystem models such as EwE.

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### Table 1. Main applications and limitations of biochemical tracer techniques used to identify parameters, patterns and mechanisms that underpin wide-scale processes in our Oceans.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Applications (advantages)</th>
<th>Limitations</th>
</tr>
</thead>
</table>
| Biochemical tracers (elements in common to all those described below; i-iv) | - Integrated trophic knowledge over time & space.  
- Geographical separation due to differences in oceanography, temperature, etc.  
- Compounds altered in predictable ways.  
- Analysis of different organism tissues can investigate diet at different time (days to years) and biological (organism to system) scales.  
- Measure and distinguish variability across the food web. Requires fewer samples than stomach content analysis and biometrics; more cost-effective.  
- Can be non-lethal (using tissue biopsies, teeth, fish scales, hairs, feathers, etc). | - Taxonomic classification problematic.  
- Biochemical incorporation dynamics and metabolic turnover rates of tissues poorly understood.  
- Requires knowledge of an organism's key prey and their biochemical composition.  
- Based on untested or unrealistic assumptions related to paucity of experimental studies.  
- Low predictive power.  
- Multiple sources with similar signatures. |
| i. stable isotopes (C, N, O, Hg) | - Trophic position estimates.  
- Dominant source (of N, C, O, etc.) identified.  
- Diet composition inferences can be obtained using Bayesian mixing models. | - Requires knowledge of isotopic values of the primary producers over space and time.  
- Patterns of isotopic fractionation unknown.  
- Overreliance of literature (baseline) values for key model parameters. |
| ii. Lipids/fatty acids (DHA, EPA) | - Provide retrospective information on stock discrimination, nutritional/physiological condition, movement patterns, and diet.  
- Identification of base of the food chain dependencies (e.g. bacteria, detritus, diatom vs dinoflagellates) and certain taxa.  
- Diet matrices obtained using statistical models  
- Can elucidate underlying physiological assumptions of other tracer techniques. | - Large number of fatty acids obtained (typically 40, but up to 70 variables).  
- Metabolic pathways (elongation and selected synthesis) of specific fatty acids not well understood.  
- Detection level of rare prey still being evaluated. |
| iii. Trace elements & contaminants | - Status of species and ecosystem health.  
- Identification of unique trophic pathways (e.g. mercury changes with depth) or prey groups (e.g. high cadmium in cephalopods). | - Require good understanding of physiological properties of the compound, in addition to physiological, life-history and environmental influences. |
| iv. compound specific amino acids | - Provide more detailed information with increased spatial resolution.  
- Estimates of trophic enrichment factors and food web baseline.  
- Elucidate underlying physiological assumptions of other tracer techniques.  
- Can better trace quantitatively minor but qualitatively important components. | - Costly, although less intensive sampling approach (than other techniques) required.  
- Precision varies dramatically between compounds, due to analytical complications (teething problems).  
- Requires sufficient separation of compounds and strict data processing.  
- Patterns of isotopic fractionation still being elucidated; need for targeted investigations. |

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MODELLING CUMULATIVE ECOSYSTEM DYNAMICS: POSTER PRESENTATIONS

TROPHIC FUNCTIONING OF SANDY BEACHES WITH DIFFERENT DEGREES OF HUMAN DISTURBANCE

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ABSTRACT

Sandy beaches are transitional environments between marine and terrestrial zones and are very dynamic ecosystems, primarily controlled by physical factors. The organisms residing in sandy beaches create significant and complex food webs, where organisms ingest diverse food sources, derived both from the sea and land, which are assimilated, egested, excreted, respired and finally converted to new biomass. Sandy beaches provide a vast array of ecological services to support human requirements, many of which

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are substantial. These ecosystems are especially vulnerable to impacts from recreation, cleaning, nourishment, urban development, pollution and exploitation. These changes might also be reflected in a disruption on the trophic structure, functioning and ecosystem dynamism. Therefore, a consideration of all ecosystem components, the energy flows and network characteristics is a fundamental aspect that should be considered when evaluating human impacts on beaches. Thus, mass-balanced models are useful tools for exploring potential impacts in environmental functioning and how these changes can be propagated through trophic interactions.

The main objective of this study was to assess the effect of urbanisation and tourist occupancy on the trophic structure, functioning and network features of sandy beaches along a human pressure gradient, using mass-balance models. In the current study, two comprehensive food webs contrasting opposite situations in terms of pressure level, were constructed for the first time. Sandy beaches are located in Cadiz Bay, on the southwest Iberian Peninsula and models comprised 27 and 28 compartments in perturbed (Valdelagrana) and protected (Levante) beaches, respectively, including detritus, phytoplankton, zooplankton, invertebrates, fishes, and birds. Estimates of the energy flows, ecosystem energetic and network properties of Levante and Valdelagrana beaches are shown in Table 1. Common features of both ecosystems were evident in the magnitude and partitioning of flows. Even though Valdelagrana had a TST that was 25% less than Levante, the percentage consumption, exports and respiratory flows remained constant between the beaches, and were predominated by consumption, followed by respiration and flows to detritus. The higher values of relative ascendency (A/C) and the internal relative ascendency (Ai/Ci) at the unperturbed beach, suggest that this area is more stable, more organised and highly developed than the urbanised beach. Also, the difference between A/C and Ai/Ci quantifies the dependency on external factors. The difference in Levante was 1% and was 10% in Valdelagrana, suggesting that the perturbed area is more influenced by external factors. Furthermore, the perturbed beach showed higher value of Overhead, which is associated with systems in earlier stages of development. Diverse trophic attributes have been also considered as possible indicators of stress (e.g., the Finn cycling index, Ascendency, System Omnivory etc.). The results showed that disturbed site had lower values of ascendency and capacity than undisturbed beach although the greatest differences between beaches were observed in the cycling capacity measured by the FCI index. In Levante, recycling was 2.3-fold higher than in Valdelagrana.

In conclusion, we have tested the potential of EwE to provide useful information to distinguish changes in ecosystem structure and functioning produced by perturbed/non-perturbed of sandy beaches. Selected beaches had the same physical, climate and morphodynamic conditions, so that the differences found could be attributed to the impact caused by the different degree of urbanisation and occupation of each beach. In general terms, the trophic functioning of both beaches was analogous, but the protected area appeared more complex, organised, mature and active than the urbanised beach. Network analysis showed that the urbanised area has a greater degree of disturbance due to the value of different indices, especially the Finn cycling index, which we suggest could be considered as an indicator of anthropic impacts in sandy beaches. The developed models provide useful information and could represent the status of the trophic functioning of two sandy beaches. Moreover, these finding highlight the importance of protected areas for the maintenance of biodiversity.

Table 1. T Comparison of main system statistics between urbanised and protected beaches.

<table>
<thead>
<tr>
<th></th>
<th>Levante</th>
<th>Valdelagrana</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of all consumption</td>
<td>288.59</td>
<td>175.64</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Sum of all exports</td>
<td>29.92</td>
<td>76.71</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Sum of all respiratory flows</td>
<td>206.94</td>
<td>119.88</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Sum of all flows into detritus</td>
<td>71.50</td>
<td>84.19</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Total system throughput</td>
<td>596.95</td>
<td>456.42</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Sum of all production</td>
<td>182.76</td>
<td>179.43</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Calculated total net primary production</td>
<td>158.83</td>
<td>158.79</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Net system production</td>
<td>-48.11</td>
<td>38.91</td>
<td>g DW m⁻² y⁻¹</td>
</tr>
<tr>
<td>Total primary production/total respiration</td>
<td>0.77</td>
<td>1.32</td>
<td></td>
</tr>
<tr>
<td>Total primary production/total biomass</td>
<td>16.84</td>
<td>28.50</td>
<td></td>
</tr>
<tr>
<td>Total biomass/total throughput</td>
<td>0.02</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Total biomass (excluding detritus)</td>
<td>9.43</td>
<td>5.57</td>
<td>g DW m⁻²</td>
</tr>
<tr>
<td>Connectance Index</td>
<td>0.21</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>System Omnivory Index</td>
<td>0.14</td>
<td>0.18</td>
<td></td>
</tr>
</tbody>
</table>
Ascendency          984 (44.2%)  739.3 (41.3 %)
Overhead            1240 (55.8 %) 1051.7 (58.7 %)
Finn's cycling index 4.08        1.74
Predatory cycling index 0.65  2.55
Finn's mean path length 2.52  2.32

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TEMPORAL AND SPATIAL VARIABILITY IN OVERFISHED COASTAL ECOSYSTEMS: A CASE STUDY FROM TANGO BAY, JAPAN

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ABSTRACT
The annual coastal fishery catch in Japan has decreased every year since peaking in 1985 (Figure 1). Two possible causes of this decline are overfishing and the deterioration of coastal environments relating to human activities. Shallow coastal areas provide important nursery habitat for juveniles of commercial coastal fishes and invertebrates. The fishery resource production system, consisting of community and food web structures, is thought to be strongly affected by changes in shallow coastal environments. Therefore, we should understand the whole system to consider measures for habitat restoration and appropriate management of resources. From this context an ecosystem-based approach to fishery resource management is vital. The objective of our research is to characterize the spatio-temporal variability in coastal biological production systems across depths and seasons using Ecopath with Ecosim (Christensen and Pauly 1992, Christensen and Walters 2004), and eventually Ecospace (Walters et al. 1999), and to use these models to assess the impact of fishing and habitat losses or deterioration on the system, and to understand how to manage coastal Japanese fisheries in a sustainable way.

We use data from Tango Bay, Kyoto Prefecture, Japan as a case study for shallow benthic coastal ecosystems in Japan. The Tango Bay ecosystem is affected by the Yura River and as such, represents a typical bay in Japan’s coastal areas. Additionally, Tango Bay has been extensively studied and detailed data on the physical environment, primary production, secondary production, ecology of important fish species and their prey organisms are available. In addition to existing data, we sampled the benthic community and surveyed environmental variables (salinity, water temperature, sediment distribution) throughout 2013 (March, June, August, October, November). Organisms were collected at depths of 5-200 m using a beam

Figure 1. Annual coastal fishery catch in Japan in millions of tons. Data from Fisheries Agency, Japan

trawl net in order to cover a broad range of variation in the habitat and species composition of the coastal ecosystem. Depth is an important variable in species composition of benthic communities (Nilsson & Rosenberg 2000). A similar set of samples was also collected in 2006. This repeated collection of benthic community and environmental data allows us to compare the biological production structure over time and will give more detailed inputs into our future Ecospace model.

The biomass information from 2006 and 2013 was used to create two separate Ecopath models for Tango Bay. Preliminary analyses show that total biomass decreased between 2006 and 2013. Additionally, the models suggest that flounder (Paralichthys olivaceus) is a keystone species in the coastal ecosystem, suggesting that management of coastal fisheries may need to carefully consider this species as a target, in order to ensure sustainability.

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ECOSYSTEM STRUCTURE AND FISHING IMPACTS IN THE NW MEDITERRANEAN SEA USING A FOOD-WEB MODEL WITHIN A COMPARATIVE APPROACH

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**ABSTRACT**

We developed a food-web model to characterize the structure and functioning of the marine continental shelf and slope area of the NW Mediterranean Sea, from Toulon to Cape La Nao (Figure 1), in the early 2000. Previously, various models were developed in the area using Ecopath approach (Bănaru et al., 2013; Coll et al., 2006) but the new model included a larger area considering important hydrodynamic events in
the region that enhance the connectivity between both regions. From a fisheries point of view, there are also some shared-stocks in the larger area, such as hake and anchovy. The model covers 45547 km² and includes depths from 0 to 1000 m.

Input data are based on local scientific surveys and fishing statistics, published data on stomach content analysis, and the application of empirical equations to estimate consumption and production rates. The model is composed of 54 functional groups, from primary producers to top predators, with three multi-stanza groups (hake, anchovy and sardine), and Spanish and French fishing fleets being considered.

Results show that the main trophic flows are associated to detritus, phytoplankton, zooplankton and benthic invertebrates. Several high trophic level organisms (such as dolphins, benthopelagic cephalopods, large demersal fishes and large pelagic fishes) and also the herbivore salama fish are identified as key groups within the ecosystem. Results confirm that fishing impact is high and widespread throughout the food-web.

The comparative approach highlights the spatial productivity pattern of the Mediterranean (higher in the Atlantic and NW basin than the SE region). Despite productivity differences, compared ecosystems share common features in terms of structure and function such as the important role of detritus, the dominance of the pelagic fraction in terms of flows and strong benthic-pelagic coupling.

**Table 1.** Statistics and ecological indicators for the NWM model.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of all Consumptions (TQ)</td>
<td>897.27</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Sum of all Exports (E)</td>
<td>1088.08</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Sum of all Respiratory Flows (TR)</td>
<td>279.55</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Sum of all Flows to Detritus (TFD)</td>
<td>1493.14</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Total System Throughput (TST)</td>
<td>3758.03</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Sum of all Production (TP)</td>
<td>1599.93</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Calculated Total Net Primary Production</td>
<td>1366.1</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Total Primary Production/Total Respiration (Pp/R)</td>
<td>4.89</td>
<td></td>
</tr>
<tr>
<td>Net System Production (NT)</td>
<td>1086.55</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Total Primary Production/Total Biomass (Pp/B)</td>
<td>32.00</td>
<td></td>
</tr>
<tr>
<td>System Omnivory Index (SOI)</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Finn’s cycling index (of total throughput) (FCI)</td>
<td>9.12</td>
<td>% of TST</td>
</tr>
<tr>
<td>Total Biomass (excluding detritus) (TB)</td>
<td>42.69</td>
<td>t·km⁻¹</td>
</tr>
<tr>
<td>Mean Trophic Level of the community (mTLco)</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Total Catches (TC)</td>
<td>4.18</td>
<td>t·km²·year⁻¹</td>
</tr>
<tr>
<td>Mean Trophic Level of the catch (mTLc)</td>
<td>3.13</td>
<td></td>
</tr>
<tr>
<td>Primary Production Required to sustain the fishery (PPR, considering PP + detritus)</td>
<td>17.36</td>
<td>%</td>
</tr>
<tr>
<td>Gross Efficiency of the fishery</td>
<td>0.003</td>
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<tr>
<td>Mean Transfer Efficiency (TE)</td>
<td>14.3</td>
<td>%</td>
</tr>
<tr>
<td>Ecopath pedigree index</td>
<td>0.62</td>
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</tr>
</tbody>
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**REFERENCES**


MODELING THE ALIEN SPECIES IMPACTS IN MARINE ECOSYSTEMS

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ABSTRACT

The invasion of alien species is increasing in coastal marine ecosystems and currently it is considered one of the main threats to the global biodiversity. Alien species can impact marine ecosystems at any biological level producing changes from genetic diversity of native species to alterations of the entire ecosystem structure.

The Mediterranean Sea is one of the main marine ecosystems altered by invasions, especially the eastern basin. Currently, there are nearly 1000 invasive species described in the Mediterranean. Human impacts such as habitat loss, pollution and overfishing add to the negative impact that invasive species are having on the ecosystems.

Various approaches have been used to model alien species impacts on marine ecosystem. At the species level, models focus on population biology questions, such as population establishment, spread, impacts and invasion control. In addition, species distribution models (SDMs) have been used to quantify the potential distribution of invasive species and predict ecologically suitable areas for them to become established.

Because of the growing appreciation of the interconnectedness between environment, species populations and human impacts, the ecosystem approaches are now considered necessary. Several tools for species interactions have been applied in biological invasions using different levels of complexity. A good example is the modeling efforts towards the ctenophore Mnemiopsis leidy in the Black Sea. Applications range from models that include a number of groups within the pelagic compartment and environmental conditions to evaluate the impact of Mnemiopsis invasion to applications that include the entire ecosystem using the Ecopath approach to evaluate the invasion, in addition to overfishing and eutrophication.

Furthermore, integrated models of network structure and nonlinear population dynamics have been used to search for potential generalities among trophic factors that may drive invasion success and failure.

The Ecopath with Ecosim approach (EwE) has been frequently used to study the impacts of invasions in marine ecosystems, in addition to a number of applications that can be found in the freshwater
environment (www.ecopath.org/models). The applications in marine environments include invasive species from low trophic levels to top-predators (Table 1). Frequently, these studies include one or two invasive functional groups and have been applied to different regions and to different ecosystems types.

The methodologies used in these EwE models represent a baseline for the DESSIM project (A Decision Support System for the management of Israel’s Mediterranean Exclusive Economic Zone) in the Eastern Mediterranean Sea. Within the DESSIM project, an EwE model of the Israel EEZ area is being developed in order to allow the study of several cumulative impacts, such as the impact of invasive species and fishing impacts, and different management options will be tested. The model is structured within 45 functional groups, 9 of them are alien groups that include several crustaceans and fish species. The model has a similar structure to other Mediterranean Sea Ecopath models in order to allow a comparison between results. Data used to construct the model include data collected from the early 1990’s through to 2012 as part of fishing trawls, scientific surveys and fisheries statistics.

Modeling invasive species within the context of a large ecosystem model of the Eastern Mediterranean represents a major challenge, as it includes the modeling of a large number of alien species found at all levels of the food-web. The period of time since the arrival of the various species greatly varies. Successful modeling of these species will provide a means for predicting the rate at which they may spread further north and westward under different environmental conditions.

Table 1. Examples of Ecopath models that have been used to study the alien species impacts in marine ecosystems. Module: 1. Ecopath; 2. Ecopath and Ecosim; 3. Ecopath, Ecosim and Ecospace.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Number of alien functional groups</th>
<th>Taxa</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gucu (2002)</td>
<td>Black Sea</td>
<td>1</td>
<td>Gelatinous plankton</td>
<td>1</td>
</tr>
<tr>
<td>Daskalov (2002)</td>
<td>Black Sea</td>
<td>1</td>
<td>Gelatinous plankton</td>
<td>2</td>
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<tr>
<td>Pranovi et al. (2003)</td>
<td>Adriatic Sea</td>
<td>1</td>
<td>Bivalvia</td>
<td>2</td>
</tr>
<tr>
<td>Falk-Petersen (2004)</td>
<td>Barents Sea</td>
<td>1</td>
<td>Crab</td>
<td>2</td>
</tr>
<tr>
<td>Arbach Leloup et al. (2008)</td>
<td>English Channel</td>
<td>1</td>
<td>Gastropoda</td>
<td>1</td>
</tr>
<tr>
<td>Lercari and Bergamino (2011)</td>
<td>Rio de la Plata Estuary</td>
<td>2</td>
<td>Bivalvia and Gastropoda</td>
<td>1</td>
</tr>
<tr>
<td>Arias-González et al. (2011)</td>
<td>Caribbean Sea</td>
<td>1</td>
<td>Fish</td>
<td>2</td>
</tr>
<tr>
<td>Pinnegar et al. (2014)</td>
<td>Bay of Calvi (Corsica)</td>
<td>1</td>
<td>Fish</td>
<td>2</td>
</tr>
<tr>
<td>Akoglu et al. (2014)</td>
<td>Black Sea</td>
<td>1</td>
<td>Gelatinous plankton</td>
<td>1</td>
</tr>
<tr>
<td>Corrales et al., in progress</td>
<td>Eastern Mediterranean</td>
<td>9</td>
<td>Crustaceans and fishes</td>
<td>3</td>
</tr>
</tbody>
</table>

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DESSIM: A DECISION SUPPORT SYSTEM FOR THE MANAGEMENT OF ISRAEL’S MEDITERRANEAN EXCLUSIVE ECONOMIC ZONE (EEZ)\textsuperscript{71}

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**ABSTRACT**

The ecosystems of the Israeli Mediterranean coastline and exclusive economic zone (EEZ) have undergone significant changes in recent decades due to numerous global and local stressors (Fig.1). The region, also known as the Levant, has the hottest, saltiest and most nutrient poor waters in the Mediterranean Sea, and marine species may be naturally close to their physiological tolerance limits thus highly sensitive to environmental change. The naturally extreme environment of the eastern Mediterranean has become even more extreme to its native species (almost all of Atlantic origin) in the past few decades due to rapid

climate change, and regional stressors such as species invasions through the Suez Canal. Communities have already shifted considerably through collapses of native species and the increasing dominance of invasive species, mainly of IndoPacific origin. Fishing has also reduced fish populations. In recent years, new threats have emerged, including large desalination plants and gas and oil platforms soon to be exploiting extensive, newly discovered, offshore energy reservoirs. Yet, through all this time, little attention has been given to the inter-linkages among the different functions and services provided by this ecosystem, at economic, social, environmental and political dimensions.

The lack of regulatory coordination among related ministries required for optimal management of this vital marine region has set the stage for multiple, and often contrasting, proposed solutions for maintaining ecosystem services while sustaining the resilience of the ecosystems in question.

The DESSIM project is a collaborative project that includes partners from IOLR and Tel Aviv University in Israel, SAMS in the UK and IRD in France and the Ecopath International Initiative in Spain. As part of the project we are developing, and applying, a series of Ecopath with Ecosim (EwE) food web models (Christensen and Walters 2004) that will enable the interrogation of the links and consequences of various cumulative impacts and management options. The models will provide governmental agencies and stakeholders the ability to diagnose the impact of potential intervention in the ecosystem in terms of management alternatives, and identify the large multi-scale impacts of change. Using these models we will provide a holistic view of the ecosystems and services contained within the Israeli EEZ. The models will be available to all interested agencies and stakeholders as we view stakeholder participation as key to successful implementation of the outcomes of the study.

The prime objective of this study is the development of key components of a decision support system for the management of Israel’s EEZ ecosystem. In order to achieve this objective we will complete the following tasks:

1. Through the merging of stakeholder participation and scientific knowledge and expertise, we will develop a series of ecosystem models of the EEZ based on the Ecopath with Ecosim suite of tools;
2. Use the models to establish a common language between stakeholders and decision makers;
3. Based on input from stakeholders, we will construct management scenarios and study their potential impact on the ecosystem using the EEZ models;
4. Attempt to merge the tools developed in the proposed study with other existing or yet to be developed tools such as biochemical models, fisheries simulation models, and visualization tools, among others.

The base Ecopath model for DESSIM has a similar structure to other Mediterranean Sea Ecopath models in order to allow direct comparison between models. The model structure contains a total of 46 functional groups and includes a separation between native and invasive species in order to allow for the study of the impact of invasive species on the ecosystem. Data used to construct the model include data collected from the early 1990’s through to 2012 as part of fishing trawls and scientific surveys.

The key issues to be examined with the EwE models include: fisheries management, size and location of marine reserves and MPAs, the impact of infrastructure (e.g. drilling rigs, desalination plants, and water treatment plants), effects of aquaculture (e.g. fish cages), the impact of invasive species, and the impact of socio-economic constraints, human behaviour and market characteristics.

It is expected that by fall 2017 we will provide stakeholders and decision makers a tool that can be used to examine the impact of different management measures on the ecosystem of Israel’s Mediterranean Exclusive Economic Zone and to evaluate optimal management strategies that include both ecological and socio-economic aspects.
Figure 1. The main stressor affecting the Israeli Mediterranean coastline and exclusive economic zone ecosystems.

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ECOLOGICAL NETWORK INDICATORS OF ECOSYSTEM STATUS AND CHANGE IN THE BALTIC SEA\textsuperscript{72}

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ABSTRACT

Several marine ecosystems under anthropogenic pressure have experienced shifts from one ecological state to another. In the central Baltic Sea, the regime shift of the 1980s has been associated with food-web reorganization and redirection of energy flow pathways. These long-term dynamics from 1974 to 2006 have been simulated here using a food-web model forced by climate and fishing. Ecological network analysis was performed to calculate indices of ecosystem change. The model replicated the regime shift. The analyses of indicators suggested that the system’s resilience was higher prior to 1988 and lower thereafter. The ecosystem topology also changed from a web-like structure to a linearized food-web.

MODELLING TROPHIC FLOWS IN THE SEINE ESTUARY: COMPARISON BETWEEN HABITATS WITH CONTRASTING IMPACT

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ABSTRACT
The evaluation of Good Environmental Status for marine and freshwater ecosystems, increasingly subject to anthropogenic impacts, is a pivotal issue in marine management. An important tool for the purpose is the modelling of flows in a food web, considering the whole ecosystem and allowing the characterization of ecological functioning applying Ecological Network Analysis (ENA). Estuaries are at the interface of marine and freshwater ecosystems, and are usually characterised by high human pressure, accompanied by high levels of anthropogenic impact. At the same time, they are of extreme importance for biogeochemical cycles and for marine resources exploitation.

Here, we present the case study of the Seine estuary, northern France, an extremely impacted ecosystem over the last decades (Fisson 2014). Following from the Rybarczyk & Elkaim (2003) work, we split the estuary into 6 spatial compartments (Navigation Channel, Northern Channel Flank, Southern Channel

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Figure 1. Map of the Seine estuary, showing the 6 modelled spatial compartments.
Flank, and 3 marine habitats in the Seine Bay) and used the Ecopath with Ecosim approach (Christensen & Walters 2004) to model the unknown flows in each of the 15 compartments. Figure 1 shows the spatial compartments that were established. Then, we calculated ENA indices for each model: total system throughput, connectance, system omnivory, Finn’s cycling index, average path length, and relative redundancy (internal overheads over total development capacity). We also identified the functional groups that perform key ecological roles in the system, by means of the keystoneness index (Libralato et al. 2006).

Results show that the two most stressed areas were the navigation Channel and the Northern Flank: the former, where the building works of the Normandy Bridge were conducted in 1988-1995, and the latter, where both the bridge construction and the extended harbour of Le Havre (Port 2000) are considered a major environmental stressors. The typical top-down control, evident in the other modelled areas, was not present in the Channel and the Northern Flank, showing instead a change in keystone roles of the ecosystem towards lower trophic levels, and higher omnivory than the other areas (Figure 2). The Southern Flank, comprising most of the National Reserve of the Seine Estuary protected area, showed instead the highest system activity (shown by total system throughput), higher trophic specialisation (shown by system omnivory), and low system stress (indicated by lower cycling index and relative redundancy). The Northern Flank is then probably the most sensible area in the estuary, in terms of vulnerability to human impact.

This work has also accomplished the objective of establishing a ‘before’ control situation from which studies on the impact of the new Port 2000 Le Havre harbour, built in the first 2000s, will be conducted in the near future. Studies before now found impacts on specific compartments of the suprabenthos (Dauvin et al. 2010), but an ecosystem-level approach was not applied until now.

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SHIFTING STATES OF A MEDITERRANEAN FOOD WEB EVIDENCED BY ECOLOGICAL NETWORK ANALYSIS

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ABSTRACT

The evaluation of food webs responses to multiple stress factors is essential to understand and define the good ecological status of ecosystems, especially for the implementation of the Marine Strategy Framework Directive (MSFD). The European project DEVOTES (DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status) partially addresses this issue, focusing on both fishing pressure and climate change impacts. Ecological Network Analysis (ENA) indices can be used as proxies of response of the ecosystem to an external stress.

A shift at both climatic and planktonic scale has been described over the whole Mediterranean Sea during the late 1980s (Conversi et al, 2010). Here, we studied patterns of ENA indices from every time step of an already-balanced food web model of the Ionian Sea, central Mediterranean (Piroddi et al, 2010) to describe its response to the shift. We extracted an Ecopath solution for each year from 1978 to 2008, of an Ecosim scenario which included catch time series, nutrient forcing, and reference CPUEs for vulnerability adjustment. System omnivory, ascendency, relative redundancy, Finn’s cycling, and keystoneness were then calculated for each year, and related to the North-Atlantic Oscillation (NAO), Northern Hemisphere Temperature (NHT), SST, and sea-level pressure (SLP).
Results showed a shift in the pattern of the ENA indices variance more than their mean. Keystoneness also showed important variations during the same period, with the widest changes occurring in the mid trophic web. Sequential t-test analysis for identifying regime shifts (STARS, Rodionov 2004) found two periods of change: one in 1991, consistent with the observed regime shifts in the Mediterranean, and another in the early 2000s, when the wide fluctuations stop. The ecosystem did respond, in the early 1990s, to some changes in the late 1980s, with an increase in omnivory and organic matter recycling.

No significant forcing by climatic variables was detected by a BIO-ENV routine. However, this does not rule out the presence of possible correlations between ecosystem properties and climatic factors. Probably a combination of other pressures, such as fisheries and/or eutrophication, might also be driving the shift. Still, these results suggest that ENA is a powerful tool for describing ecological status and to inform strategies for management of marine ecosystems.

**Figure 1.** Keystoneness of each group for the time series. The circles represent the biomasses.

**Figure 2.** Regime shift detection for each indices. The blue lines represent the time series anomalies. The orange lines represent the stewise trend showing the regime shift in the mean or the variance detected by STARS method.
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POTENTIAL IMPACTS OF GLOBAL CHANGES ON BRAZILIAN CONTINENTAL SHELF AND SLOPE COMMUNITIES

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ABSTRACT
Global environmental changes associated with the emissions of fossil fuels are manifesting throughout the oceans as changes in temperature, salinity, pH, sea level, and primary production. These changes are expressed uniquely and heterogeneously in any given marine or coastal setting, and are expected to affect particular populations of interest and entire biological communities. Global climate change affects even the deep sea, as observed by Gille, from 700 to 1100 m depth, in addition to widespread effects perceived on the ocean’s surface. The intensity of effects on each species, population, and individual is mediated by its sensitivities and tolerances to the direct effects, and by indirect effects via biological relationships, mainly trophic relationships. The effects of global changes can thus occur both directly or indirectly on populations, with further effects on the entire communities (Polis and Winemiller 1996; Ruiter et al. 2005). Because each species has unique environmental tolerances, the effects of the local manifestations of global changes will be species-specific and locally-specific, and will lead to re-shuffling of species and changes in ecosystem-function (Pörtner 2002, Hobday 2011, Okey et al. 2014). In the present pilot exploration, we examined the effects of projected global changes in primary production on a Brazilian continental shelf food web model constructed by Nascimento et al. (2012), given three scenarios of global temperature change, at this stage without knowledge of local and spatial heterogeneity and without explicit knowledge of tolerances and sensitivities of particular functional groups other than how changes in primary production cascade through the present model tropically.

We examined three scenarios of changes in primary production, two of them extreme and one intermediate. We selected the highest value Princeton/Marra et al. (2003) (1.096), the lower value Princeton/Poly (0.989), and the intermediate Princeton/Dunne (1.046). For each value, we made the simulations using the global changes scenario of lower (1.4°C) high (5.8°C) and intermediate (3.6°C) temperature increase. These temperature increase scenarios were based on IPCC SRES scenarios. Global change, specially temperature, is believed to have impact on ecosystem health (for instance, increasing acidification, decreasing O₂ concentration, and altering habitat arrangements and species distribution (Cheung et al., 2009; MacNeil et al., 2010), besides altering metabolic rates directly. We ran the simulations for 50 years with and without the global change scenarios, while maintaining the current level of fisheries. The simulations without global change, indicated increases in the initial biomass (2001) of Cutlasfish in 15 times, Tile fish in 14 times, Blackfin goosefish in 13 times, Scianidae in 7 times and

Modelling cumulative ecosystem dynamics

Searobin in 3 times over the course of 50 years. Also we observed the collapse of Large benthic pelagic fishes in 2039, and the strong decrease of the biomass of several functional groups as: Hake adult and juvenile; Red porgy; Antigonia capros; Ariomma bondi; Genypterus brasiliensis; Synagrops sp.; Squid and Demersal fishes. This was attributed to fisheries pressure, in Nascimento et al. (2012).

The simulations that specified global changes in primary production also indicated increases in the biomasses of the same functional groups, but at a different magnitude, depending of the scenario. The scenario that simulates the largest increase in primary production (Princeton/Marra et al 2003) resulted in the largest Scianidae biomass value among the three scenarios of primary production, mainly when we consider the more optimistic scenario of increased mean temperature (+1.4°C) (increase 75 times the initial biomass). However, as we increase the temperature, the increase in the final biomass of Scianidae is reduced (70 times the initial value). Although the increase is a little lower when we apply higher temperatures, the resulting high biomass is a response to indirect effects of changes in other interacting functional groups. We believe this is caused by the effect of Scieniidae on the benthic community, that supports a large portion of the ecosystem. Temperature made no difference in the scenario specifying an intermediate level of primary production (Dunne). In all simulations, the final biomass of the Sciaenidae, after 50 years, was about 67 times larger than the initial value. Similar results were observed when we specified the reduction of primary production (Princeton/Poly). These simulations showed a biomass of Scianidae 59-60 times larger than the initial value.

All simulations showed the extinction of some functional groups. Blackfin goosefish; Tile fish; Benthic pelagic fishes; the Pink cusk-eel Genypterus brasiliensis; Blackmouth basses Synagrops sp.; Squid and Predator crustaceans. These functional groups were especially sensitive to the specified global changes. Some of the extinctions occurred during the first ten years, depending of the proposed scenario and temperature. In the Dune scenario, the rapid extinction of Blackfin goosefish was more related to changes in primary production than to the temperature. The simulations using the primary production lower than the current levels (Princeton/Poly) result in the reduction of the biomasses of many more species than the simulations implying the increase of the primary production. These reductions in primary production also strongly reduce the biomasses of lower trophic level functional groups because these groups are composed by detritivores and their immediate consumers. It makes sense in a scenario that reduces the primary production, especially because in this model of a slope ecosystem all primary production is converted in detritus. For some species, such as the Blackfin goosefish, accounting for global changes in productivity leads to the best fit of the simulated trajectory with the observed trajectory over the last 10 years, especially the simulation with the largest increase in primary production. Work by Ainsworth et al. (2011) indicate that the combined effects of changes in multiple climate variables have a strong effect on the ecosystem of north Pacific. Their simulations, that combined multiple factors, led to estimated decreases in landings in the order of 77% in a moderate climate effects scenario, and by 85% in a severe climate effects scenario. Simulated changes in individual effects led to much weaker responses.

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Assessing the impact of hydroelectric dams on Amazonian rivers using Ecopath with Ecosim: a case study of the Belo Monte Dam

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ABSTRACT

Freshwater ecosystems are being intensively modified and degraded by human activities around the world (Cowx, 2002). More than 70% of all the rivers in the temperate zone have been modified to a high degree (Dynesius and Nilsson, 1994), and similar tendencies have been observed in tropical systems (e.g. Castello et al., 2013). Among the many threats to the biological integrity of freshwater ecosystems, the construction of dams appears to be one of the worst types of impact for the biodiversity of tropical rivers (Hoeinghaus et al., 2008; Castello et al., 2013).

The Xingu is considered to be one of the Amazonian rivers with the greatest potential for the generation of hydroelectricity, which has led to the construction on this river of the world’s third largest hydroelectric project, the Belo Monte dam, on the mid-section of the river. This project has a long history of controversy, which has resulted in numerous delays and modifications, making it one of the region’s most contentious engineering works. This is because the impacts of the project on the region’s environment, biota, and human populations will be intense and definitive, requiring adequate description and monitoring, based on reliable scientific data, for the dependable evaluation of the project’s impacts.

The aim of the present study was to obtain a holistic picture of the ecosystem of the middle Xingu River by identifying its main functional groups and tracing and quantifying the flow of biomass through the system. A dynamic simulation was then developed to predict the impacts of the Belo Monte dam on the local ecosystem.

Three criteria were considered for the definition of the system to be modeled: (a) hydrological and geographic affinities; (b) the availability of data obtained during the experimental sampling (2006-2007) of the components of the system to be modeled, and (c) the area used by fishery activities on this stretch of the river. The model was developed for the period of the river’s highest discharge (February–May), when the alluvial forest is flooded seasonally. The spatial limits of the ecosystem to be modeled with the area to be affected by the Belo Monte hydroelectric project were defined using a geographic analysis of the landscape units, resulting in the delimitation of an area of 1,629 km2. In order to integrate the available information on biomass, production, consumption, food spectrum, and dynamics of the populations of the principal species found in the system, a trophic steady state model of 24 components was constructed using Ecopath with Ecosim software. The results indicate that the main flow of biomass into the food web is by alluvial forest. However, other sources of primary production, such as the epilithon, were also important. The model had four distinct trophic levels (Figure 1).

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Figure 1. Trophic model of the aquatic ecosystem of the middle Xingu River within the area affected by the Belo Monte hydroelectric project. The size of each circle corresponds to that of its contribution to the biomass of each compartment. The numbers correspond to the trophic level of each compartment.

A simulation of the effects of a gradual process of suppression of the alluvial forest, which would accompany the filling of the Belo Monte reservoir (Figure 2), indicated an increase of the epilithon, in the case of the primary producers. In the case of the consumers, the benthic scrapers and iliophagous fish increased, while frugivorouso fish, which constitute an important source of animal protein for human consumption, declined. In addition to a general loss of biodiversity, then, the model indicates clearly the potential loss of fishery productivity on the stretch of the river that will be affected by the inundation of the Belo Monte reservoir.

Figure 2. Simulation of the reduction in the biomass of the alluvial forest and its effects on select compartments of the ecosystem.

REFERENCES


Modelling cumulative ecosystem dynamics

CUMULATIVE EFFECTS OF ENVIRONMENTAL AND HUMAN ACTIVITIES IN THE SOUTHERN CATALAN SEA ECOSYSTEM (NW MEDITERRANEAN) ASSOCIATED WITH THE EBRO RIVER DELTA

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ABSTRACT
Biodiversity, natural resources, and ecosystem services change in response to stressors such as climate change and cumulative human activities. Species distribution models and ecosystem models (Guisan and Zimmermann, 2000; Fulton, 2010) are two methodologies that are being developed to further the study of these cumulative impacts. However, to date available methodologies offer limited capabilities to work jointly to produce integrated assessments that take both food web dynamics and spatial-temporal environmental variability into account.

Recently, a new development into Ecospace spatial-temporal dynamic module of EwE, the habitat capacity model, has enabled a new implementation of the spatial-temporal model Ecospace (Christensen et al., Submitted). This new development offers the ability to spatially drive foraging capacity of species from the cumulative impacts of multiple physical, oceanographic, and environmental factors such as depth, bottom type, temperature, salinity, oxygen concentrations, primary production change, etc. Afterwards, the food web dynamics are considered along with fisheries impact. This development bridges the gap between envelope environmental models and classic ecosystem food-web models.

In this study we apply the new habitat capacity model to evaluate the combined impact of changes in environmental conditions, in addition to fishing impact, in the ecosystem dynamics of the Southern Catalan Sea, located in the NW Mediterranean Sea. The Southern Catalan Sea ecosystem is dominated by the productivity dynamics of the Ebro River that flows into the area forming a wide delta. Therefore, we included salinity, temperature, primary production, and oxygen as main environmental factors in the

habitat capacity model, in addition to depth and distance from the coast) and substrate type (seagrass, mud, sand and rock/coarse mixed sediments) (Figure 1). Using the new temporal-spatial framework developed to allow geographic information data to drive Ecospace layers (Steenbeek et al., 2013), we were able to vary the main environmental factors over time.

We used a previously developed Ecopath model (Coll et al., 2006) fitted to time series of data from 1978 to 2010 (Coll et al., 2013) as a baseline scenario to run the original Ecospace temporal-spatial dynamic model and predict species distributions and abundances. Afterwards, we ran the new habitat capacity model from 1978 to 2010, and results based on the original Ecospace and the new habitat capacity model were compared. Results were evaluated to mainly assess the influence of changes associated with environmental factors linked with the Ebro River delta dynamics, such as primary production, salinity and temperature, in the pelagic compartment of this marine ecosystem, since the pelagic compartment has a fundamental importance in the dynamic of Mediterranean marine ecosystems (Coll et al., 2008).

Results illustrate the importance of including detailed environmental dynamics into food web modelling approaches, in addition to human activities, to realistically predict species distribution and abundance. This study contributes to progress enable more reliably predictions of changes in marine ecosystems under scenarios of global change, explicitly taking environmental changes and food-web direct and indirect interactions into account.

Figure 1. Example of the habitat capacity model being applied to the Southern Catalan Sea EwE model. The figure shows the salinity environmental layer and the functional response for anchovy.

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Gulf of Mexico Species Interactions (GoMexSI): Integrated ecosystem trophic data for Ecopath models and ecosystem based fisheries management

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ABSTRACT
Many Ecopath models have been created world-wide since the program was developed in 1984 (Polovina 1984). One very significant commonality is their reliance on diet data for the species or functional groups being modeled (Pauly et al. 2000). Each time a new model is constructed, diet data must either be searched for anew, or, if one is lucky, use and/or modify the diet matrix from a previous model. The former process can be quite time consuming. In addition, time constraints prevent one from examining all

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of the data available for a particular system to be modeled, except in rare cases. And, there is the time consuming process of evaluating and normalizing the data to fit specific project needs.

We report on the Gulf of Mexico Species Interaction (GoMexSI) database and webpage (gomexsi.tamucc.edu) (Simons et al. 2013) that can streamline the process of diet data acquisition for future Ecopath models in the Gulf of Mexico. While the database aims to include all types of species interactions (e.g. predator/prey, host/parasite, commensal, mutualist, amensal, etc.), we are currently focused on predator-prey interactions, most notably those of fishes. See Table 1 for a complete list if all taxa that are part of the database model. The database is being constructed by extracting species interaction data from historical reference material (peer reviewed literature, government reports, theses and dissertations, etc.), and from contributed datasets or databases from scientists willing to share their data. Data are explicitly geo-referenced, that will allow for use in Ecospace models.

Currently there are 37,930 interactions recorded, from 61 references/contributors. This represents 1,346 unique interactors. Data can be queried and viewed in a summarized format online (Figure 1a), or the raw data downloaded via a csv file. In addition, there are query pages for spatial queries (Figure 1b) and exploration of predator and prey for specific species (Figure 1c). We have been working with Ecopath, Atlantis, and OSMOSE modelers recently in an attempt to provide much needed, but hard to find, predator and prey data. Future plans include tools to allow the download of diet matrices for use in the Ecopath modeling environment.

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<th>Taxon</th>
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<th>Number of References Identified</th>
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<th>Number of Species Cited</th>
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Through a NOAA Marine Fisheries Initiative grant we are currently examining diet data shortfalls through taxonomic and spatial gap analyses, and adding new data through stomach content analyses at University of South Florida and Texas A&M University-Corpus Christi. Many of these data are being targeted for an Atlantis model under development by PI Ainsworth, and will be useful for other Ecopath and OSMOSE models under development for different regions of the Gulf.
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Figure 1. Screen shots of GoMexSi query pages: a) the taxonomic query, b) the spatial query, and c) the exploration mode. All queries were run on *Scomberomorus cavalla* (king mackerel).

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END-TO-END MODELLING: ORAL PRESENTATIONS
THE GLOBAL OCEAN IS AN ECOSYSTEM: SIMULATING MARINE LIFE AND FISHERIES¹

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ABSTRACT

There is considerable effort allocated to understanding how climate change impacts our physical environment, but comparatively little to how life on Earth and ecosystem services will be impacted. We developed a spatial food web model of the global ocean, spanning from primary producers through to top predators and fisheries with the primary aim to evaluate how alternative management actions may impact sea food supply for future generations.

We developed a modeling complex to initially predict how global seafood production may be impacted by environmental parameters and fisheries combined, and initially evaluated the model performance through hindcasting (Christensen et al., Submitted).

The modeling complex has a food web model as core, obtains environmental productivity from a biogeochemical model, and assigns global fishing effort spatially (Figure 1). We tuned model parameters based on Markov Chain random walk stock reduction analysis, fitting the model to historic catches. We evaluated the goodness-of-fit of the model to data for major functional groups, by spatial management units, and globally. As a first step we evaluated how well the modeling complex could replicate historic catches. Spatially by LME, these results showed that in 1950 catches were concentrated in the northern hemisphere and Asia (Figure 2). Coastal biomasses of large fish notably decreased in coastal areas with high effort since 1950.

The model could replicate broad patterns of historic seafood production with best agreement for the total catches, good agreement for species’ groups, and with more variation at the regional level. It is likely that improvements to the global fleet database will improve the spatial effort distribution. This modelling complex can eventually be used for evaluating the combined impact of fisheries and climate change on upper-trophic level organisms in the global ocean, including invertebrates, fish and other large vertebrates.
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TROPHIC IMPACT AND KEYSTONE SPECIES IN TWO PELAGIC COMMUNITIES IN THE NORTH CHILEAN PATAGONIAN COASTAL SYSTEM²

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ABSTRACT
We built Ecopath models that includes from bacteria to marine mammals for two south marine Patagonian ecosystems. Our objective was to determine the different role of the planktonic and benthonic species in the structuring and functioning of the pelagic marine communities in two coastal ecosystems. We estimated the mixed trophic impact matrix and keystone index for different marine species of the Inner Sea of Chiloé – ISCh and, Moraleda Channel – MCh (Fig. 1). Each Ecopath models included 4 small-scale fisheries and 36 functional groups, and was built with Ecopath with Ecosim 6.0 (see Pavés et al., 2013).

Mixed trophic impact analysis.
In both models, Euphausiacea positively affected the Mysticeti (baleen whale), and Scyphomedusae negatively impacted the larval fish group, its food item. In addition, a negative effect of one group on itself (higher intra- than inter-group competition for resources or cannibalistic behavior) is observed for Gadiformes, Otariidae, Aves, and O. orca. Indirect effects can be detected for microphytoplankton, which had a negative effect on the biomasses of heterotrophic and autotrophic nanoflagellates (HNF and ANF) but a positive effect on the microflagellates because the latter group predates moderately on microphytoplankton but strongly on HNF and ANF. The bacteria in these ecosystems had a positive impact on their predators, the microbial loop species, and a negative impact on their unique food source, the DOM reservoir; however, bacteria had a very strong intraspecific effect. The ANF positively impacted the zooplankton group and, in turn, higher trophic levels (i.e., fishes and top predators), and even produced an increase in fishery activities. Microphytoplankton produced the same effect as ANF on these groups, but this effect was 57-64% stronger on the fishes, marine mammals, and fisheries than ANF. Thus, microphytoplankton had a stronger impact on ecosystem productivity and showed more efficient trophic flows than ANF. A similar situation was determined with Copepoda

Figure 2. Keystone for the functional groups of the pelagic communities in the Inner Sea of Chiloe (ISCh) and Moraleda Channel (MCh), sensu Libralato et al. (2006). For each functional group, the keystone index (“y” axis) is reported against overall effect (“x” axis). Overall effects are relative to the maximum effect measured in each trophic web. Thus, for the “x” axis, the scale is between 0 and 1. The keystone functional groups are those that have value close to or greater than zero, and they are numbered in the graph. 3 = Orcinus orca; 15 = Ichthyoplankton (L); 16 = Scyphomedusae; 17 = Hydromedusae; 26 = Copepoda calanoida. In bold and cursive correspond to ISCh and MCh, respectively.

Keystone index

In the ISCh and MCh ecosystems, the Scyphomedusae, Hydromedusae, Copepoda calanoida, O. orca and Ichthyoplankton were estimated to be the groups with high keystone indices (Fig. 2). Despite of this general trend described in the trophic impact, it was indeed possible to observe differences and similarities between models. For example, changes in bacteria and ANF biomasses produced the same (or similar) impact on both the ISCh and MCh food webs. But, in the others high trophic level groups this trophic impact is higher in the ISCh’s predators than preys, or higher in MCh’s preys than predators (microphytoplankton, Copepoda calanoida, Euphausiacea). The jellyfish trophic impact was stronger for the ISCh’s (~20-90%) than MCh food webs. On the other hand, change in the biomass of Clupeiformes and Gadiformes, affected mainly the MCh than the ISCh fisheries activities (~15-100%). In addition, changes in top predators’ biomass would affect mainly their prey and the fisheries, with the effect being more intense in the MCh compared to the ISCh (~50%). In both models, the keystone indices were similar. In this study it was possible to highlight the importance of the plankton and nekton species for the structure of marine ecosystems, and to demonstrate the key role of the microbial loop over traditional food web in the functioning of the marine Patagonia food webs. This is the first time where one model is considering the components of the traditional food web (fishes, marine mammals, sea birds), fisheries activities (small scaled fisheries) as well as the microbial food web (macroplankton, mesoplankton, microplankton, nanoplankton, picoplankton) in order to better understand their relationships and roles in the functioning of the marine pelagic communities.

ACKNOWLEDGEMENTS

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Modelling the potential effects of climate change on the Western Scotian Shelf ecosystem, Canada

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ABSTRACT
Climate change is expected to cause profound changes in marine ecosystems that will vary in magnitude and effect among regions. We are using an EwE model to explore the potential effects of climate change on the western Scotian Shelf ecosystem in eastern Canada with two scenarios of climatic changes. The model included the effects of temperature, pH, oxygen, decreased primary productivity and change in zooplankton size structure. These factors had differential, and sometimes opposing additive effects on the functional groups and species. The results also illustrate how the effects of climate change can be further enhanced or ameliorated by predator-prey interactions. At the individual species or functional group level, some effects were negligible, but at the ecosystem level, the combined predicted effect of climate change on the western Scotian shelf led to a reduction in biomass of 19% to 29% with an associated decrease in catches of 20% and 22%. Dramatic declines in biomass due to climate drivers could be alleviated in part by a 50% decrease in exploitation rate. We discuss the pros and cons of this approach, how this type of analysis can be used to advice fisheries management, and propose next steps for this work.

ACKNOWLEDGEMENTS
The project was funded by Fisheries and Oceans Canada Aquatic Climate Change Adaptation Services Program (ACCASP). We would like to thank Carie Hoover for tremendous help with climate data extraction and some programming. We also thank other members of the ACCASP project and “Assessing the abilities of Ecopath with Ecosim models to identify climate impacts to upper trophic level species in Canada’s marine ecosystems” for helpful discussions in which Cam Ainsworth and William Cheung also contributed. The procedure Multi-sim was developed as a permanent plugin in EwE during this project. Thanks to reviewers who helped improve this manuscript with their judicious comments.

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BRIDGING THE GAP BETWEEN ECOSYSTEM MODELLING TOOLS AND GEOGRAPHIC INFORMATION SYSTEMS: DRIVING A FOOD WEB MODEL WITH EXTERNAL SPATIAL-TEMPORAL DATA

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ABSTRACT

It is becoming clear that climate change and human activities will have notable impacts on marine ecosystems in the future, but the extent is poorly understood. Research is challenged by the limitations of present-day ecosystem models to address the interrelated spatial dynamics between climate, ocean chemistry, marine food webs, and human systems.

The work presented here, the spatial-temporal data framework (Steenbeek et al., 2013), is part of a larger study to develop a new approach to model interoperability for closing the gap between marine ecosystem modelling tools via geographic information systems (GIS) technology. The approach we present simplifies interdisciplinary model interoperability by separating technical and scientific challenges into a flexible and modular software approach (Figure 1).

To illustrate capabilities of the new framework, we use a remote-sensing derived spatial and temporal time series to drive the primary production in a marine ecosystem Ecopath with Ecosim food web model of the North-Central Adriatic (Figure 2).

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In general, the predictive capabilities of the food web model to hind-cast ecosystem dynamics are enhanced when applying the new framework by better reflecting observed species population trends and distributions. Results show that changes at the phytoplankton level due to changes in primary production cascade up the pelagic food web. Highly exploited demersal species such as European hake do, however, not show clear signs of cascading. This may be due to the high fishing pressure on this species and the resulting strong historical decline in the area.

The development of the new framework is a promising step toward future implementations of a model interoperability framework.

**REFERENCES**

AN INTERMEDIATE COMPLEXITY, PHYSICALLY COUPLED END-TO-END MODEL PLATFORM FOR COASTAL ECOSYSTEMS

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ABSTRACT
How can we compare the roles of the physical environment and the complex network of trophic interactions in the regulation of pelagic ecosystem dynamics? We have developed a spatially explicit, intermediate complexity food web model platform that integrates physical and biological processes. Our aim has been to define physical and biological components generally enough to allow consistent comparisons among diverse ecosystem types (upwelling, downwelling, shallow bank, semi-enclosed sea) but still encompass the essential physics and trophic structure of each ecosystem. We present an application of the model platform to the Northern California Current upwelling ecosystem, drawing upon independent surveys of nutrient dynamics, plankton dynamics, and variability in higher trophic level community composition to define trophic relationships. Seasonal upwelling of nutrients has long been recognized as the primary driver of ecosystem productivity. The physical model therefore uses seasonal cycles of upwelling, mixed layer depth, advection through the spatial domain, and light intensity as ecosystem drivers. However, long-term plankton time-series observations suggest a strong role for ocean basin-scale physical processes (Pacific Decadal Oscillation, ENSO) in regulating lower trophic level dynamics that are outside the capacity of regional-scale ecosystem models to incorporate directly. Observations of plankton dynamics from long-term monitoring surveys are incorporated directly into the model to study the effects of basin-scale physical processes upon local energy flow patterns and higher trophic level production rates.

ECOPATH models estimate energy flow along each trophic linkage of the food web based on predation demand of each consumer upon each of its prey groups. A mass-balanced ECOPATH solution for the food web is a map of consumption demands of upper trophic levels upon lower levels for every consumer-prey

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pair. It is mathematically simple to transform a top–down linear solution (ECOPATH) into a donor-driven map of production fate up the food web (Steele 2009). Further, with the addition of nutrient pools as functional groups fed primarily by the microbial metabolism of detritus, it is possible to account for nutrient cycling (with care of proper conversion between nitrogen and wet weight currencies between the nutrient and living functional groups). This is a true end-to-end model in that it models the flow of production across all trophic levels from the input of nutrients into the system, to the production of plankton, higher trophic level consumers and fisheries, and back to recycled nutrients.

A model expressed in this format may be used to estimate the efficiency of energy (biomass) flow between different portions of the food web, to quantify the importance of functional groups as energy transfer nodes between lower and upper portions of the food web, or to show the short-term consequences of changes to plankton dynamics, community variability or other energy flow rearrangements in the food web. We have been referring to the transformation of an ECOPATH model to this format and the analyses performed as ECOTRAN (“ECOPATH transform”) models (Steele & Ruzicka 2011). We have applied steady-state ECOTRAN analyses to studies of the Northern California Current upwelling ecosystem off the northwest coast of the United States. The model incorporates annual pelagic survey data and fishery databases (pacfin.psmfc.org, recfin.org) to infer the trophic relationships between >100 groups, representing the pelagic and benthic communities and 17 fisheries. Metric analyses include investigation of interannual differences in energy transfer efficiencies through the food web and differences in the importance of key groups (euphausiids, forage fishes, and jellyfish) as energy transfer nodes (Ruzicka et al. 2012). Scenario analyses have included investigations of the consequences of expanding whale populations, seasonal jellyfish blooms, and changes in forage fish abundance (e.g., Ruzicka et al. 2013).

Our first goal is to test ecosystem sensitivity to variability in the rates of nutrient cycling and export of plankton production. In particular, we are interested in sensitivity to the time-scale of variability among physical processes, retention processes that moderate the export of plankton production, and variability in the rate nutrient recycling via microbial metabolism of detritus. Figure 1 demonstrates a preliminary exploration of zooplankton and forage fish response to alternate plankton retention and detritus recycling rates in models driven under identical daily upwelling, mixing, and light regimes. Under high retention rates (25% reduction of advective transport) and detritus recycling (75% of pelagic detritus production rate), the rates of copepod and forage fish production are doubled. Evaluation of lower trophic parameterization, including plankton retention, is made against nutrient, chlorophyll, and zooplankton surveys across the central Oregon (USA) shelf.

Applications of this model platform are being extended to comparative studies of the Georges Bank, Gulf of Alaska, and North Sea ecosystems. With a comparison of these ecosystems under identical physical frameworks, we hope to evaluate the relative roles of the physical setting against the trophic network structure in the dynamics of diverse coastal ecosystems.

Figure 1. Model-estimated mid-shelf copepod and anchovy biomasses in the Northern California Current 2003-2005. Heavy black time-series represents model run under high detritus recycling and plankton retention settings. Light blue time-series represents model run under high advection, low detritus recycling settings.
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TWO-WAY COUPLING OF EwE IN FORTRAN WITH AN INTERMEDIATE COMPLEXITY NPZD MODEL

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ABSTRACT

We describe the details of recoding of EwE in Fortran (EwE-F) and compare its reliability against standard EwE (Christensen et al., 2008) through comparative model simulations. Further, we provide an example of coupling EwE-F with an intermediate complexity NPZD-type model (Cossarini and Solidoro, 2008). The EwE-F allows to dynamically link a Higher Trophic Level (HTL) representation of an ecosystem with the Lower Trophic Level (LTL) one including a more realistic representation of biogeochemical cycles. The coupled test case in this work considers an intermediate complexity LTL model involving double compartments of limiting nutrient (dissolved organic and inorganic phosphorous), of detrital forms (organic phosphorous particulate and sediment), as well as of phytoplankton and zooplankton, (N2P2Z2D2) plus bacteria and the HTL EwE-F module that comprises 35 functional groups. The results of the coupling exercise highlighted the following key points: i) the necessity of careful tuning and calibration of closure terms of the LTL model and the consumption and mortality rates of the HTL model in the final coupled scheme; ii) importance of reconsidering the predation on detrital compartments by the HTL ones; iii) importance of considering the excretions and mortality flows from HTL compartments to detrital ones; iv) reconciling the time step differences between the two models of the coupled scheme; v) adjusting the HTL model currency to conform with the model currency of the LTL model in the final coupled scheme.

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**EwE MODELS IN AUSTRALIA**

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**ABSTRACT**

A decade or two ago, ecosystem models had a hard time being accepted. There may be still some resistance and that stigma goes back to very early times when EwE models were in formative stages both in terms of capturing ecosystem dynamics and validating the data and predictions. But the tide has turned and we are seeing fisheries and environment managers turning to ecosystem scientists and modellers for strategic advice. In Australia, in particular EwE and Atlantis (Fulton et al. 2004), have been used mostly to inform management strategies as in Fulton et al. (2007) rather than as a tool to synthesise large amounts of data. We discuss some examples where EwE models have been used in Australia and how their results are being reported in high-profile science publications and raising both the profile and the legitimacy of these models.

Many models have been developed around Australia now: from the prawn fishery in the Great Barrier Reef system (Gribble 2003) and the GBR coastal ecosystem (Gehrke 2007), the Eastern Tuna & Billfish Fishery (Griffiths et al. 2010) and New South Wales fisheries (Forrest 2008) off eastern Australia; the Gulf of Carpentaria (Bustamante et al. 2011, Dichmont et al. 2013), Darwin Harbour (Martin 2005) in northern Australia; the North West Shelf (Bulman 2009) and Jurien Bay (Lozano-Montes et al. 2011) in western Australia; the Great Australian Bight (Goldsworthy et al. 2013), Port Phillip Bay (Fulton 2004) and Phillip Island, West Bass Strait (Bulman et al. 2012) and Eastern Bass Strait (Bulman et al. 2006) and three in Tasmania (Bulman et al. 2002, Metcalf 2009, Watson et al. 2013) in southern Australia.

Currently, a collaborative project between WA Marine Science Institution and CSIRO is developing an EwE model for the marine domain of the Kimberley region of Australia to be integrated with an ALCES model for the terrestrial domain (Carlson et al. 2014). These models will be used in a Management Strategy Evaluation framework to inform management, particularly focussed on the cumulative effects of human uses and activities and acknowledging climate change. The first tentative use of a collection of EwE models for this then-emerging issue of climate change was that of Brown et al. (2010), where a number of models, of varying degrees of complexity and integrity, were used to investigate the effects of climate change on primary productivity. This publication was one of the first to highlight the value of EwE models in assessing the impacts of climate change in Australia.

Most recently, one of the most contentious issues to have arisen in Australian fisheries is that of the attempt to use a large industrial freezer trawler in the Small Pelagic Fishery. Embedded in the very vocal public outcry that ensued, was a degree of uncertainty regarding the exploitation rates of the target species in the Fishery and the possible ecosystem effects. Of course these issues weren’t new nor confined to

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Australia. The Lenfest Ocean Program and the Marine Stewardship Council (MSC) both had commissioned investigations into the sustainable management of forage fisheries and using lower trophic level species respectively well before but it was the first time that forage fishes had caught the attention of the Australian public at large. CSIRO Wealth from Oceans Flagship lead a collaborative global project exploring the broad ecosystem effects of fishing under Fisheries Assessment Methodology-like harvest strategies on low trophic level species i.e. small pelagic “forage” fishes, squid and krill, in five ecosystems around the world (Smith et al 2011). In each system there were two models used, one of which in each system was an EwE model. The reason to use two models was “to avoid conclusions being dominated by structural assumptions in particular types of models” (Smith et al. 2011).

The South Eastern Australian case study (Johnson et al. 2010), compared the EwE Eastern Bass Strait model and the Atlantis South East Australian model. We ran simulations using both models, systematically depleting LTL groups to specified percentages of their unfished biomass i.e. B75, B40, B20 and B0. Significant ecosystem impacts i.e. changes in relative biomasses of >±20%, were found for trophic groups by heavily depleting LTL species (down to B0) as you might expect, but significant impacts could be produced at lower rates of depletion for mesopelagics and krill particularly in EwE. Model parameterisation and structure explained some of the results - LTL groups that were initially more abundant had the greatest ecosystem impact when they were depleted. The “reactiveness” of EwE compared to Atlantis was also a factor, though overall they both suggested roughly the same number of groups would be impacted (though not always the same groups).

Nevertheless, the resulting publication followed soon after by “Little Fish, Big Impact”, a comprehensive global analysis which included 72 EwE models (Pikitch et al. 2012) has magnified the focus of management advisory committees on the utility of good ecosystem models. In Australia it is becoming acceptable practice to use multiple modelling platforms, such as Atlantis and EwE, such as in the MSC study in strategic assessment of marine ecosystems.

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The Marine Stewardship Council partly funded the project “Developing best practice management for low trophic level fisheries: evaluation of harvest strategies.”

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USING ECOPATH WITH ECOSIM AND ECOSPACE TO MODEL THE RESPONSE OF EASTUARINE NEKTON TO MULTIPLE HABITAT RESTORATION SCENARIOS IN BARATARIA BAY, LOUISIANA, USA

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ABSTRACT

Louisiana’s coastal ecosystem has a long historical record of productive fisheries. Since the early 20th century, the coast has endured multiple perturbations resulting in many unforeseen ecological consequences (Day et al. 2007). One such consequence is the loss of marsh vegetation in southern Louisiana (LA). Marsh habitats are thought to play a role as nursery habitats for post-larval and juvenile fishes, providing both refuge from predation and increased foraging opportunities (Teal 1962, Gunter 1967, Nixon 1980, Boesch and Turner 1984, Houde and Rutherford 1993, Zimmerman et al. 2002). The effects of continued marsh loss on estuarine food webs is an important topic for state management agencies. In 2012, the LA Legislature adopted LA’s 2012 Comprehensive Master Plan for a Sustainable Coast, a report that details over $50 billion of restoration efforts that would increase the sustainability of its coastal communities and ecosystems. Building on the foundation of the 2012 Coastal Master Plan, improvement efforts are now underway for the 2017 Coastal Master Plan. One of the major expansions for the 2017 Coastal Master Plan is the inclusion of an ecosystem model that would predict potential responses of estuarine nekton and oysters to various restoration scenarios put forth by the Master Plan. These restoration scenarios vary in scope, but many propose to increase total area of marsh and to return the estuary to previously observed salinities. This study developed a preliminary model whose architecture will be used to develop the Fish and Shellfish Model for the 2017 Coastal Master Plan.

Adding to an existing ecosystem model in Barataria Bay, LA, USA (Lewis 2014), we used Ecopath with Ecosim and Ecospace (EwE) to simulate possible future restoration scenarios in this system. Our Ecopath model is a snapshot of the Barataria Bay food web in the year 2000. In Ecosim, we calibrate the model to relative biomass data, landings data, fishing effort, and environmental data (salinity, temperature, and NO2 + NO3 (NOx)). Using the calibrated model from Ecosim, we then developed an Ecospace model that includes environmental driver data (salinity and linear distance of marsh edge) using the new and flexible spatial-temporal data framework (Steenbeek et al. 2013) in EwE.

An important component of this model is its ability to expand to greater spatial extent using real GIS data, with the intent to develop a coast wide ecosystem model in LA. In addition, the capability to create a spatially and temporally explicit model allows investigators to explore a wide range of restoration scenarios that will give state management agencies a range of possible outcomes to consider. Here, we

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developed multiple restoration scenarios using geo-referenced salinity data, output from the 2012 Coastal Master Plan hydrodynamic models. We also incorporated geo-referenced marsh data that shows the changing marsh landscape over time (Couvillion et al. 2011). Using these data, we created three future scenarios in Ecospace that represent varying degrees of restoration, or no restoration at all.

Preliminary results of this study indicate that estuarine nekton respond more readily to changes in salinity than to changes in marsh edge distance. These results, interpreted together with previous studies that tested the influence of marsh land on nekton production (Lewis 2014), could prove valuable to state managers who select restoration projects moving forward. The ability to adjust salinity gradients in coastal LA using freshwater diversions already in place (i.e. Caernarvon and Davis Pond), could be a more cost effective approach rather than rebuilding marsh land that has been previously lost.

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This work is funded by the Water Institute of the Gulf in support of the development of the 2017 Coastal Master Plan Fish and Shellfish Community model.

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MANAGING LAKE ECOSYSTEM BY USING A FOOD-WEB MODEL – LAKE KINNERET AS A CASE STUDY

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ABSTRACT
Lake Kinneret is a freshwater lake located in the northern part of Israel. The lake is one of the most important freshwater resources in Israel, and as a result a stable ecosystem is of prime importance. The ecosystem has, however, changed dramatically during the last 20 years. Certain species of phytoplankton that used to be part of the food-web stopped blooming regularly and toxic species started appearing frequently (Kamenir et al., 2007; Roelke et al., 2007; Zohary et al., 2012). In addition, in 2008 the catch of commercial fishes was the lowest ever measured in the lake (Shapiro, 2009). One of the most important fish species in the lake is Sarotherodon galilaeus or in its commonly known as St. Peter’s fish (Ben-Tuvia et al., 1992). This species has the highest market value of all lake species. But it is also valued as an important player in helping to maintain water quality (Hambright et al., 2002). And indeed, one of the lake management strategies include stocking millions of S. galilaeus fingerlings every year though the effect of that action on the ecosystem is unknown.

In order to understand the ecosystem interactions and to provide management recommendations a food-web model using Ecopath with Ecosim was developed as part of a project intended to provide lake managers with a tool for testing management strategies for the lake. The static, mass-balance, Ecopath model of the lake included all tropic levels from detritus and bacteria up to the top predators and commercial fisheries. All together there were 29 groups in the model that included 7 phytoplankton groups, 3 zooplankton functional groups, all commercial fish’s species and top predators like the catfish and cormorant birds.

During a scientific conference held in 2008 it was claimed that the cormorant (Phalacrocorax auritus) which feed on lake fishes every year from November to March are partly responsible for the decline in catch in 2008 and therefore a massive action of removal from the lake surroundings should be taken. We used the food-web model to estimate the impact of the cormorants on the ecosystem by running 2 scenarios: at first to evaluate the biomass and catch of St. Peter’s fish during the period 2013-2030 under assumption that the phytoplankton, fingerling stocking, number of cormorants and the fishing effort will remain at 2012 levels. In the second scenario the future conditions remained the same as the first scenario but cormorants were removed from the system.

By comparing the two scenarios we were able to estimate the long-term effect of cormorant exclusion if it were to be implemented and provide the stockholders with recommendations regarding this action. The results of the comparison between the two scenarios were unexpected and provided insight into the complex food-web interactions taking place in the Lake Kinneret food-web. The interactions highlight the need for an ecosystem model in order to evaluate possible management actions.

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TOWARDS AN ECOSYSTEM APPROACH TO FISHERIES IN THE NORTHERN HUMBOLDT CURRENT SYSTEM\textsuperscript{10}

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ABSTRACT

From 2004-2008, an international cooperation between Peruvian and European scientists (project “CENSOR”) aimed to model the Northern Humboldt Current System (NHCS) using updated data sets, and with a focus on the impacts of the El Niño Southern Oscillation (ENSO) to resources dynamics. Using Ecopath with Ecosim (EwE), trophic models of the NHCS included the following explorations: 1) Comparison of normal upwelling and warm ENSO phase (“El Niño”) ecosystem states (Tam et al. 2008), and 2) Dynamic exploration of historical temporal dynamics (Taylor et al. 2008a). In order to achieve these goals, various working groups at the Instituto del Mar del Perú (IMARPE) integrated historical data to the common modelling framework, included estimates of biomass, productivity, mortality, diet, and other parameters.

The main results of the work were insights into energy cycling, the impact of ENSO on ecosystem size and functioning, and estimates of trophic control configurations for important predator-prey interactions (e.g. bottom-up vs. top-down). Predator-prey configurations (i.e. vulnerability settings) were based on a tuning of these settings to historical time series (1996-2003), and provided an important preliminary step towards using the model for predictive purposes. The models also allowed for the comparison of the NHCS to smaller nearshore subsystems in Peru (Taylor et al. 2008b,c) and to other eastern boundary upwelling systems in terms of the drivers to dynamics (Shannon et al. 2008).

These first works were viewed as initial steps in for further ecosystem-based management scenarios. Subsequently, the model has been used for some preliminary explorations focusing on important fisheries resources, including: 1) Predictions of the degree of recovery of the heavily exploited Peruvian hake to reductions in the fishery (Tam et al. 2009), 2) Assessment of the trophic importance of anchovy to other ecosystem components (Tam et al. 2010), and 3) Assessment of the ecosystem impacts of fishing on small pelagic fish (Smith et al. 2011). This work continues these explorations at the ecosystem level through explorations across various fleets and resources.

The earlier iteration of the model will be updated in several ways in preparation for further management explorations: 1) Extension of time series up to the present (1996-2013) will permit a more robust fitting of vulnerability settings; 2) Further incorporation of multi-stanza life histories for key functional groups; 3) Development of environmental mediation functions (e.g. sea surface temperature (SST) as a mediator of phytoplankton functional groups; thermocline depth as a mediator of anchovy vulnerability to pinnipeds, seabirds, and fishery).

Using this updated model tuned to historical dynamics, we explore optimal strategies for managing the different fleets of the NHCS in terms of ecological, economic and social criteria. We also explore short-term strategies for dealing with ENSO-related variability (i.e. ENSO), and propose strategies for incorporating spatial dynamics by using habitat preference information linked to environmental data (i.e. via Ecospace).

REFERENCES


CARBON FLUXES OF TWO PELAGIC COMMUNITIES IN THE NORTH CHILEAN
PATAGONIAN COASTAL SYSTEM

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ABSTRACT
We built Ecopath models from bacteria to marine mammals for two south marine Patagonian ecosystems. Our objective was to study the role of different marine functional groups for the trophic carbon fluxes through the pelagic food webs in Patagonia ecosystems. The models were built for The Inner Sea of Chiloe – ISCh and, Moraleda Channel – MCh (Fig. 1). Each Ecopath model included 4 small-scale fisheries and 36 functional groups from bacteria to whales (see Table 1; Paves et al. 2013).

The functioning of both ecosystems was similar but the biomass and carbon flows were twice as high in the basin with large size (>20 µm) (ISCh) phytoplankton compared to the system with small-size (<20 µm) phytoplankton (MCh).

Biomass
The ISCh total biomass was ~1.5 times higher than in the MCh (13.5 g C m⁻² vs. 8.9 g C m⁻²; Table 1). While in the MCh, the biomass was greater for top predators (up to 19 times), Gadiformes (1.4), Hydromedusae (1.4) and Copepod nauplii (2.6), the ISCh showed higher biomasses of microplankton (2.3 times more), bacteria (2.0), nanoflagellates (2.0), Copepoda (1.7), and secondarily to Carangidae (3.5), Ichthyoplankton (1.9), Clupeiformes (1.7), Sciaenidae (100%), and Atherinopsidae (1.7) (Table 1).

When we compare the biomasses of microphytoplankton, nanophytoplankton (ANF), and picophytoplankton (bacteria) in the ISCh and MCh, we obtained ratios of 7.8: 1.0: 3.6 and 5.7: 1.0: 3.2, respectively. This suggests a higher dominance of the microphytoplankton (mainly diatoms) in the ISCh than in the

Figure 1. Study area in the Chilean Patagonian fjords and channels region, showing the two contrasted basins: Inner Sea of Chiloe (ISCh, 41–43°S) (upper panel) and Moraleda Channel (MCh, 43–46°S) (bottom panel). The black circles show the sampling sites for organisms from the microbial and traditional food webs.

MCh. In addition, in the ISCh ecosystem, the biomasses of the diatoms, autotrophic nanoflagellates, and bacteria constituted 7.4%, 0.9%, and 3.4% of the total biomass, unlike the MCh, where the percentages were lower (4.6%, 0.8%, and 2.6%, respectively) (see Table 1; Paves et al. 2013).

Table 1. Data output on biomass (B, mg C m\(^{-2}\)) for the different groups that represent the pelagic subweb of Inner Sea of Chiloé (ISCh) and Moraleda Channel (MCh). Bold numbers denote the data estimated by the EwE models.

<table>
<thead>
<tr>
<th>ISCh</th>
<th>MCh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otariidae</td>
<td>22.2</td>
</tr>
<tr>
<td>Gadiformes (A)</td>
<td>1311.1</td>
</tr>
<tr>
<td>Appendicularia</td>
<td>9.3</td>
</tr>
<tr>
<td>Cop. nauplii (L)</td>
<td>33.4</td>
</tr>
<tr>
<td>Aves</td>
<td>15.3</td>
</tr>
<tr>
<td>Gadiformes (J-L)</td>
<td>353.9</td>
</tr>
<tr>
<td>Siphonophore</td>
<td>28.5</td>
</tr>
<tr>
<td>Ciliophora</td>
<td>55.8</td>
</tr>
<tr>
<td>Orcinus orca</td>
<td>0.01</td>
</tr>
<tr>
<td>Carangidae</td>
<td>588.4</td>
</tr>
<tr>
<td>Salpida</td>
<td>3.6</td>
</tr>
<tr>
<td>Microphyto</td>
<td>997.4</td>
</tr>
<tr>
<td>Mysticeti</td>
<td>0.3</td>
</tr>
<tr>
<td>Clupeiformes (J-A)</td>
<td>2466.2</td>
</tr>
<tr>
<td>Decapoda (L)</td>
<td>893.9</td>
</tr>
<tr>
<td>Microflagellates</td>
<td>43.9</td>
</tr>
<tr>
<td>Delphinidae</td>
<td>0.4</td>
</tr>
<tr>
<td>Clupeiformes (L)</td>
<td>146.4</td>
</tr>
<tr>
<td>Euphausiacea</td>
<td>1556.6</td>
</tr>
<tr>
<td>HNF</td>
<td>206.4</td>
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<tr>
<td>Gempylidae</td>
<td>11.0</td>
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<tr>
<td>Ichthyoplankton (L)</td>
<td>2071.7</td>
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<tr>
<td>Chaetognatha</td>
<td>17.8</td>
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<tr>
<td>ANF</td>
<td>127.1</td>
</tr>
<tr>
<td>Sciaenidae</td>
<td>359.7</td>
</tr>
<tr>
<td>Hydromedusae</td>
<td>85.3</td>
</tr>
<tr>
<td>Cladocera</td>
<td>45.4</td>
</tr>
<tr>
<td>Bacteria</td>
<td>453.3</td>
</tr>
<tr>
<td>Atherinopsidae</td>
<td>60.9</td>
</tr>
<tr>
<td>Hydromedusae</td>
<td>23.8</td>
</tr>
<tr>
<td>Cop. calanoida</td>
<td>1197.7</td>
</tr>
<tr>
<td>DOM</td>
<td>3450.35</td>
</tr>
<tr>
<td>Ophidiformes</td>
<td>266.6</td>
</tr>
<tr>
<td>Ctenophora</td>
<td>3.5</td>
</tr>
<tr>
<td>Cop. cyclopoida</td>
<td>61.9</td>
</tr>
<tr>
<td>Detritus</td>
<td>5750.6</td>
</tr>
</tbody>
</table>

**Carbon fluxes to the detritus.**

We determined that the amount of matter that flows to detritus was dependent on the functional groups considered. In ISCh and MCh, the total planktonic and nektonic organisms produced \(\sim 699\) and \(376\) g C m\(^{-2}\) year\(^{-1}\) of detritus, respectively, of which 63% and 59% were in the form of DOM and the rest was POC (Fig. 2). The microbial loop (ciliates, microflagellates, nanoflagellates, bacteria) produced 31% (ISCh) and 23% (MCh) of this detritus, mainly as dissolved excretion (DOM) products. In these systems, the microphytoplankton produced 65% and 70% of the detritus, i.e., \(\sim 234\) and \(137\) g POC m\(^{-2}\) year\(^{-1}\) as phytodetritus and \(\sim 216\) and 126 DOM g C m\(^{-2}\) year\(^{-1}\) as exudates, respectively (Fig. 2). In the ISCh and MCh, the average annual detritus (POC, DOC) production by the chitinous and gelatinous zooplankton was 3-4% and 1-2%, respectively. Thus, chitinous zooplankton produced 8 and 6 POC g C m\(^{-2}\) year\(^{-1}\) and 11 and 9 DOM g C m\(^{-2}\) year\(^{-1}\) in these two systems. On the other hand, gelatinous zooplankton produced between \(\sim 7\) and 5 g POC m\(^{-2}\) year\(^{-1}\) and \(\sim 2\) and 1 g DOM m\(^{-2}\) year\(^{-1}\) in the MCh and ISCh, respectively (Fig. 2). The fish groups and top predators produced only 1% and \(\sim 0.006\) of the detritus in both ecosystems (mainly POC detritus), i.e., the fishes produced \(\sim 6\) and 4 POC g C m\(^{-2}\) year\(^{-1}\) and the top predators produced \(\sim 39\) and 45 DOM mg C m\(^{-2}\) year\(^{-1}\) in ISCh and MCh, respectively (Fig. 2). This means that microphytoplankton contributed 90% of the total POC, the micro- and mesoplankton groups added 7%, and the nekton (fish, top predators) contributed 3% in these ecosystems. Microplankton also produced 49% and 56% of the DOM in ISCh and MCh, and the pico- and nanoplankton were responsible for 46% and 38% of this total DOM.

In this research it was possible to highlight the importance of the quality and size spectrum of plankton on the structure of marine ecosystem, and to demonstrate the key role of the microbial loop over traditional food web in the functioning of the carbon biological pump in Patagonia ecosystems.

This is the first time where a model considers all components of the traditional food web (fishes, marine mammals, sea birds), fisheries activities (small scaled fisheries) and of the microbial food web (macroplankton, mesoplankton, microplankton, nanoplankton, picoplankton) in order to understand their relationship and role in the functioning of the carbon biological pump.
ACKNOWLEDGEMENTS

We thank our many colleagues who provided the data, information, and constructive input that allowed us to construct the trophic models for the southern coastal system of Chile. The authors are indebted to all persons who have been working on the development of the Ecopath approach since the early 1980s, especially Carl Walters from the Fisheries Centre (University of British Columbia, Vancouver, Canada). Principal author (HP) acknowledges the assistance provided by Jeroen Steenbeek, Shawn Booth, and Andrés Cisneros during his postdoctorate research at the Fisheries Centre (UBC). This study was funded by the CIMAR-Fjords Program (grants 9, 12, and 13); FONDAP-COPAS No. 15010007 Etapa II; Programa Financiamiento Basal PFB-31/2007; OCEAN CERTAIN Project EU-FP7 603773 and FONDICYT No. 1080187, and by the office of Research and Development (Universidad Austral de Chile). HJP was supported by the Postdoctorate Program 2011 - Fondecyt No. 3120100 during the conduction of this research.

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MODELLING THE POTENTIAL BENEFITS OF MARINE RENEWABLE ENERGY INSTALLATIONS

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ABSTRACT

The deployment of offshore structures for renewable energy generation (wind/wave/tidal) will lead to the alteration of access to the area of installation (Jay, 2009) for several users of the sea including: shipping, tourism and recreational users. However, potentially the largest impact will be upon the fishing industry where access loss may lead to displacement and reduced catch per unit effort, which may in turn cause conflict. To prevent conflict, it is important to investigate mitigating factors. Marine renewable energy devices (MREDs) and associated infrastructure will be placed on the seabed, affecting benthic infauna and epifauna, which are important sources of food for many species including many of commercial importance, potentially offering benefits to the fishing industry which may mitigate the causes of conflict. The effects are likely to differ between sectors, but the two key plausible benefits of MREDs are the ‘artificial reef effect’ and the ‘exclusion zone effect’ (Alexander, 2012).

The aim of this study was to investigate whether MREDs could benefit the fishing industry and help mitigate conflict by providing: a) habitat through the ‘reef effect’ and b) protection through the ‘exclusion zone effect’? Further work examined the differences between impacts at an ecosystem level (west coast of Scotland shelf) and at a smaller spatial scale - the installation level (Gulf of Corryvreckan). These studies used the Ecopath with Ecosim (EwE) model of the west coast of Scotland (Alexander et al., under review) in combination with Ecospace, a dynamic spatial version of Ecopath, to run simulations.

The key findings of the research was that it is currently not possible to definitively state whether the ‘opportunities’ of MREDs would mitigate potential negative effects. The values generated by the model were quite variable, particularly at the different spatial scales, and not always reliable. However, studies at the difference scales did suggest that overall fishing catch value was unlikely to vary greatly in response to the installation of MREDs. However, these studies show the functionality of ecosystem modelling to investigate this issue.

REFERENCES


End-to-End modelling

WHAT NEXT?

VILLY CHRISTENSEN
ELISABETH A. FULTON
MARTA COLL

At 30 the EwE approach can safely be said to be mature. But where to next?

This session is a chance for the EwE community to highlight the things just around the corner, but also to identify what is missing, what is needed, what would be an exciting extension. This will be an “all in” discussion on the future of EwE, encouraging a group discussion on where the software and approach should go from here.
What next?

WHAT NEXT? POSTER PRESENTATIONS

IMPROVING THE EBFM TOOLBOX WITH AN ALTERNATIVE OPEN SOURCE MASS BALANCE MODEL

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ABSTRACT
As ecosystem-based fisheries management (EBFM) moves from the theoretical stage towards implementation the need for flexible tools will increase. The main tools utilized for EBFM are ecosystem models. Ecosystem models can address many questions not typically covered by more traditional fishery models such as how alternative management policies may impact the ecosystem both directly and indirectly. Among a wide range of ecosystem models, a common approach for fisheries related questions are aggregate or box models, including a popular representation of the ecosystem as a mass balance model. Popularized by the Ecopath with Ecosim (EwE) model first developed by Polovina (1984) then later expanded by Walters et al. (1997, Christensen & Walters 2004), mass balance models use a series of equations to balance the energy flow through a system ensuring that energy is conserved. EwE has many strengths including its ease of use both in terms of set-up and run time due to a convenient user interface. In addition, EwE is open source which means that there is universal access to the code and the code can be

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redistributed and subsequently improved by any interested users. This form of open collaboration makes EwE a powerful tool. However, a major drawback to modifying the EwE code is the Microsoft Visual Basic platform upon which it is built. Many ecologists do not have the skills necessary to modify the code to tailor the model to their needs. Through collaboration between the Alaska Fisheries Science Center and the Northeast Fisheries Science Center, we introduce a complementary product to EwE built on a more familiar software platform, R. R is a rapidly growing open source statistical language that is familiar to many ecologists. Once fully developed, the new R package, called Rpath, will allow users to fully customize their models to meet their needs. The base version of Rpath will have the Ecosense routine developed by Aydin et al. (2007) included. Ecosense uses a Bayesian framework to address uncertainty in input parameters allowing for a creditable interval around model outputs. R has the advantage of allowing fully customizable outputs of publication quality without switching between software packages. Here we demonstrate the similarities and differences between EwE and Rpath by developing models for two ecosystems: the Gulf of Alaska and Georges Bank. We simulated a 50 year period using current fishing scenarios and compared the standard outputs from EwE and Rpath. The added flexibility of Rpath complements EwE, especially to communicate uncertainty and give users and managers a more complete picture of the state of our knowledge of ecosystem dynamics. Therefore, further development of this flexible tool that integrates statistical analysis and visualization tools in one package will be extremely useful in bridging the gap from theory to practice.

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ECOBASE: A REPOSITORY SOLUTION TO GATHER AND COMMUNICATE INFORMATION FROM EwE MODELS

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ABSTRACT
Ecological studies are more and more based on data-driven methodologies, relying on pre-existing large datasets and allowing for new insights on complex or underlying phenomena at global scales (Christensen et al. 2009). We are facing environmental degradation world-wide, and research has to be conducted at a
large or global scale to tackle these issues. However, open-access, digital and cross-disciplinary datasets are still lacking for ecology to actually join the other historical “Big” sciences, such as astronomy (Thessen & Patterson 2011). Nevertheless, authors demonstrated that published papers making available their data are cited more frequently (Piwowar et al. 2007), and incentives for digitization of non-digital materials through the use of metadata and repositories have been growing (Thessen & Patterson 2011).

The Ecopath Research and Development Consortium (ERDC) initiated the project of an Ecopath with Ecosim (EwE) models repository. However, only partial information on published models was included on the web-page, and the structure was not in place for extensive data sharing. Indeed, EwE models integrate several types of data: descriptive data on species abundance, diet composition and catch; computed data on species production, consumption and ecotrophic efficiency as well as ecosystem properties; and simulation data on species biomass trends after applying alternate scenarios. These data are required to build a model and run scenarios, and they are often only provided in supplementary materials, which are not always easily accessible. Besides, each EwE model is also associated with a particular ecosystem with specific characteristics, as well as a corresponding publication. The former information represents critical metadata when one wants to conduct a meta-analysis, yet it is not systematically provided by the modelers.

Thus, EcoBase was developed with the intention of making published models discoverable, accessible and reusable to the scientific community. The main goals of EcoBase are to (i) gather published EwE models; (ii) communicate on EwE modeling research; (iii) facilitate meta-analyses based on EwE models. In EcoBase, we built a framework where all critical metadata may be stored, in a standardized and granular fashion, so that they can be reused as criteria based on which models can be selected for future meta-analyses. EcoBase is meant to be used by ecosystem modelers worldwide as a platform where to (i) look for published EwE models; (ii) select and access models of interest to one’s research work; (iii) download other’s models as well as upload one’s own models. Overall, EcoBase will provide an online repository where to make your own model discoverable, accessible and reusable to the scientific community, as soon as it is published. We believe EcoBase may thus contribute to create synergies and enhance collaborations within the EwE community.

REFERENCES


OVERVIEW OF WORLDWIDE APPLICATIONS OF THE ECOPATH WITH ECOSIM APPROACH USING THE ECOBASE MODELS REPOSITORY

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ABSTRACT

Ecological studies are more and more based on data-driven methodologies, relying on pre-existing large datasets, and allowing for new insights on complex or underlying phenomena at global scales (Christensen et al. 2009). Yet, open-access, digital and cross-disciplinary datasets are still lacking for ecology to actually join the other historical “Big” sciences, such as astronomy (Thessen & Patterson 2011). Nevertheless, incentives for digitization of non-digital materials through the use of metadata and repositories have been growing (Thessen & Patterson 2011). The Ecopath with Ecosim (EwE) modelling approach has been applied to hundreds of ecosystems worldwide. Thus, the Ecopath Research and Development Consortium (ERDC) initiated the project of an EwE models repository (www.ecopath.org/models). However, only partial information on the models was included on the web-page, and the structure was not in place for extensive data sharing. Indeed, EwE models integrate several types of data, such as descriptive data on species abundance, diet composition and catch, or computed data on species production, consumption and ecotrophic efficiency. These data are required to build a model, but they are often only provided in

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EcoBase allowed us to give an overview of the published EwE models worldwide. For each of the 427 referenced models in EcoBase (Figure 1), we collected, standardized, and stored available critical metadata in the models repository. We focused on four main aspects: (i) the general characteristics of the modelled ecosystems; (ii) the complexity and structure of the model; (iii) the research questions considered and specific analyses performed with the models; and (iv) the publication(s) associated to the models. The recorded metadata corresponding to each aspect were compiled for all models. As expected, 70% of the models represent ecosystems between the 80s and the 2000s. 84% of the EwE models were built to analyse marine ecosystems, and 15% freshwater ecosystems. About half of the published models are located in tropical zones, and the most represented region is the Northern-central Atlantic Ocean. Most Ecopath models comprise from 10 to 30 functional groups. Time dynamic versions were developed in Ecosim for 41% of the models, and spatially-explicit versions in Ecospace for 7% of the models. We showed that 85% of the models were developed to answer questions regarding the functioning of the ecosystem, 63% to analyse fisheries and 33% to focus on particular species of interest. Less than 10% of the referenced models represent Marine Protected Areas. Such a global and synthesised overview of the published EwE models may help to better understand the usage of and interest for the EwE modelling approach in the peer-reviewed literature.

Figure 1. Localization of the 427 referenced EwE models in EcoBase

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**Programming with EwE: Customizing EwE for Your Science**

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**Abstract**

The Ecopath with Ecosim modelling approach (EwE) is celebrating its thirtieth birthday in 2014 (Polovina, 1984). Via its easy to use desktop version the EwE approach has become the most widely used food web model around the world (Christensen and Pauly, 1992; Christensen and Pauly, 1993; Walters et al., 1997; Walters et al., 1999; Pauly et al., 2000; Christensen and Walters, 2004; Christensen and Lai, 2007; Christensen et al., 2008; Christensen and Walters, 2011). However, the EwE approach can be used, extended, and applied in an endless number of ways by those with a bit of software programming experience. We wish to promote this with this short paper.

In 2006, the EwE software had reached its technical limits, and a Lenfest-funded four-year project was launched to overhaul the existing software with the following aims: (i) improve technical and scientific extensibility; (ii) extend the lifespan of the approach; (iii) facilitate connectivity to other software; (iv) improve ways to deploy and release the software; and (v) improve usability. The source code was migrated to the Microsoft .NET platform, and user interface of the software was redesigned, and a new version of Ecopath with Ecosim, version 6, was released in 2007 (Christensen and Lai, 2007).

Unknown to most users, this migration unlocked a range of new possibilities. Internally the software was modularized, which allowed construction of different user interfaces to interact with the model, or to drive the model with different databases. The new .NET code base facilitates construction of other programs that use the building blocks of EwE. The .NET language itself allows the EwE code to be executed on operating systems other than Windows. Additionally, a plug-in system was added to allow external, user-created modules to dynamically integrate with the running EwE model without requiring changes to the actual source code of EwE (Figure 1).

These capabilities are slowly being adopted by a select group of technical scientists, yielding a wide range of new analytical modules, applications, and ways to look at ecosystem model results (Figure 2). We wish to raise awareness of these new capabilities, and stimulate EwE users to start developing custom modules to further their research. We encourage our users to starting build plug-ins to extract computed results right from running simulations, to bridge EwE to other tools such as R or Matlab, or to automate the tedious process of running of a gazillion simulations.

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Via courses and user support contracts with the Ecopath Research and Development Consortium we invite users of EwE to start programming. Why not start customizing EwE for your science today?

Figure 2. OceanViz - a new way of looking at EwE model results.

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Walters, C., Pauly, D., Christensen, V., 1999. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems 2, 539-554.
THE ECOPATH RESEARCH AND DEVELOPMENT CONSORTIUM:
THE FUTURE OF EWEE5

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ABSTRACT

The Ecopath with Ecosim modelling approach (EwE) is celebrating its thirtieth birthday in 2014 (Polovina, 1984), and its twenty-fourth year as desktop software (Christensen and Pauly, 1992; Christensen and Pauly, 1993; Walters et al., 1997; Walters et al., 1999; Pauly et al., 2000; Christensen and Walters, 2004; Christensen and Lai, 2007; Christensen et al., 2008; Christensen and Walters, 2011). During these years the freely available and open source software has been supported in a variety of ways: via university and NGO budgets; by dedicated research positions; and via many, many hours of voluntary contributions by scientific users. However, since its first release as desktop software the Ecopath approach could always count on some measure of core funding to ensure its continuity.

This changed in 2010, when a four-year Lenfest Future Oceans-funded project to modernize the Ecopath approach came to an end. Through this project Ecopath version 6 was released as a modern incarnation of the old familiar tool, recast into a modular model creation toolbox, designed for extensibility and model interoperability. With 6000+ users in 150 countries and more than 700 peer-reviewed publications, Ecopath was the most popular food web modelling framework, rebuilt to take on the world, but was left without any financial means to continue.

As a response, the Ecopath Research and Development Consortium was established in 2011 as a global, cooperative network focused on the research, development and sustainability of the Ecopath with Ecosim (EwE) approach and software, its information basis, and complementary activities and capabilities. The Consortium was founded in 2011 to (i) advance the development of the EwE software; (ii) provide support to the users of EwE; and (iii) contribute to research and development of ecosystem-based management with a focus on EwE.

The Consortium undertakes several EwE-related activities, such as (i) maintaining and developing the EwE software; (ii) providing user support and organizing co-development; (iii) organizing training courses

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and conferences; (iv) developing and evaluating professional standards and best practices of EwE applications.

In order for the Ecopath with Ecosim approach to continue, the EwE approach relies on continued involvement of its users. Through the Consortium users of the EwE approach are encouraged to become actively involved in shaping the future of EwE. Contact us for implementing new functionality, or to organize a course with you at your institute. For users that wish to become deeper involved in the EwE ecosystem we encourage Consortium membership. Joining the Consortium is voluntary and is without obligations, and membership is open to any institute or enterprise that wishes to support the Consortium activities and mandate. Becoming a member just requires signing a Memorandum of Understanding, which formalizes an expression of intent to support the Consortium mandate, which can be obtained by contacting the Consortium.

With the Ecopath Research and Development Consortium, the EwE approach has become a true open-source, peer-reviewed scientific software, supported by a broad base of scientists around the world. We hope to see you becoming involved in shaping the future of EwE with us.

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