LEIBNIZ CENTRE
for Tropical Marine Research

Report

Ecological Network Analysis (ENA) Workshop

NETWORK MODELS FOR (SOCIO-) ECOLOGICAL SYSTEM ASSESSMENT AND MANAGEMENT – COMPARING TROPICAL AND TEMPERATE CONTEXTS

September 19 - 21, 2018

Leibniz Centre for Tropical Marine Research (ZMT) GmbH
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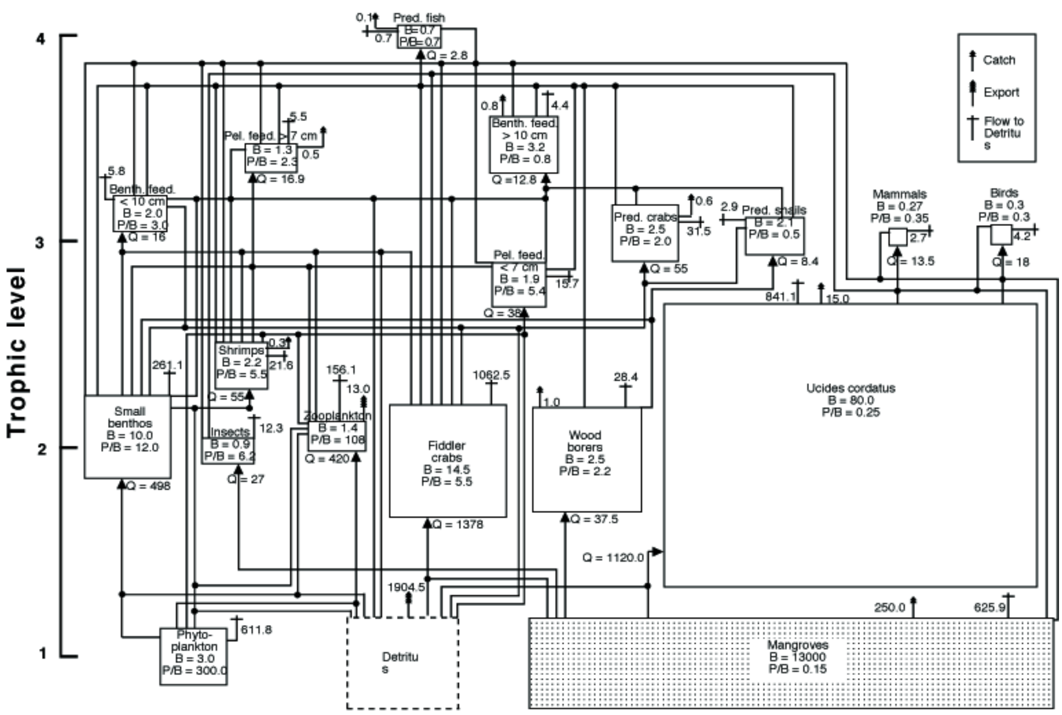

Caete Mangrove Ecosystem, Brasil (Wolff et al. 2000)

Suggested citation:

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Contents

1.Introduction

Ecological Network Analysis (ENA) combines modeling and analysis used to investigate the structure, function, and evolution of ecosystems and other complex systems.
Once the ecosystem network has been constructed, the performance of the system as a whole can be evaluated by using ENA indices. These indices represent the development capacity, degree of redundancy or specialization of flows in the network (e.g. Ulanowicz 2004).The field has grown since the late 1960ties/early 1970s and has strongly radiated into different research areas. Several different software tools are available which can calculate ENA indices such as NETWRK (Ulanowicz and Kay 1991) and R package enaR (Borrett and Lau 2014). In a recent review of the literature by Borrett et al. (2018) ENA – research was found to be mainly focused on food webs (mainly aquatic), urban metabolism, and ecosystem theory. The review shows ENA to be a topically diverse and collaborative science domain with great potential for contributing to ecological theory and to environmental impact assessment and management.

The following figure from the paper of Borrett et al. (2018) nicely shows the topical clusters identified

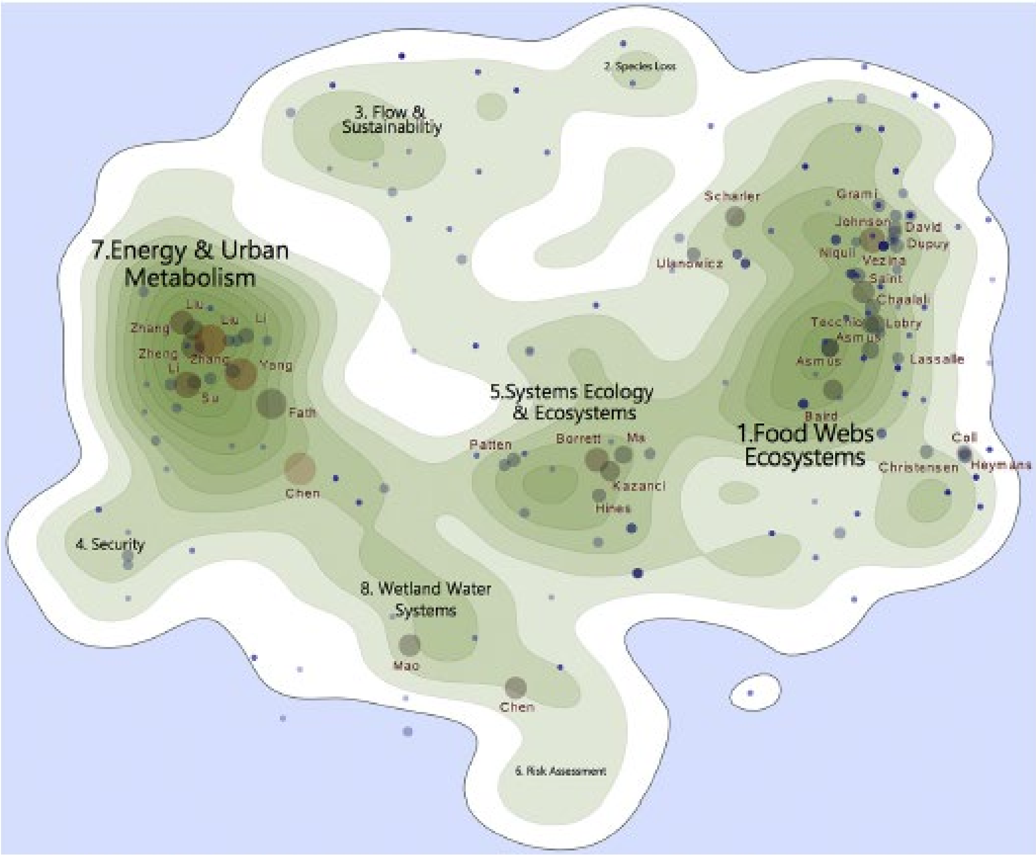

Fig. 5. Contour plot of the topic network in which nodes are papers and network edges indicate a co-term similarity. Peaks indicate topic clusters, which are labeled with cluster numbers and descriptive terms. Selected author names were placed at the centroid of the papers they authored. Greater detail about each cluster can be found in Tables 1 and 2.

Since those early years of ENA, fisheries biologists, in seeking to go beyond the single species fisheries assessment and to placing the fishery in the ecosystem context, aimed at the development of modeling tools that allow to quantify the trophic interactions within food webs and to assess the ecosystem impact of the fishery. Polovina (1984) pioneered this attempt by using a biomass pool approach, connecting functional compartments via a diet matrix and balancing the flow of energy through the food web by equating the biomass production with internal consumption and export to the fishery. He called this approach ECOPATH, which was then, during the next decade, enriched by the input of the theories of Ulanowicz (1986, 1997, 2004) mentioned above concerning growth and development of natural systems and was further developed by Christensen & Pauly (1992) and later by Walters et al. (1997), who provided the basis for the simulation software Ecosim (EwE). The ongoing further development of EwE is centered at the Ecopath International Initiative, a non-profit research association established to secure the long-term development of EwE (see https://ecopath.org/about/) As of January 2018, EwE has an estimated 8000 users in over 170 different countries and well over 800 publications in ISI Web of Knowledge, making EwE an important modelling approach to explore ecosystem related questions in marine science. For all these reasons, Ecopath was recently recognized as one of NOAA's top ten scientific breakthroughs in the last 200 years. EwE has three main components: *Ecopath* – a static, mass-balanced snapshot of the system; *Ecosim* – a time dynamic simulation module for policy exploration; and *Ecospace* – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. The Ecopath software package can be used to a) address ecological questions; b) evaluate ecosystem effects of fishing; c) explore management policy options; d) evaluate impact and placement of marine protected areas; e) evaluate effect of environmental changes.

Part of EwE is EcoBase, an open-access database of Ecopath with Ecosim (EwE) models published worldwide in the scientific literature and which was created in 2015 by a group of scientists interested in conducting global meta-analyses based on existing EwE models (see the presentation of Kolding in this workshop) . Since 2014, EcoBase is managed and supported by the members of the model repository working group of the Ecopath Research and Development Consortium (ERDC). A most concurrent development in the push to demonstrate the capabilities of EwE modelling in Europe as support to policy advice produced by the International Council for the Exploration of the Sea (ICES) was the *Workshop on operational EwE models to inform Integrated Ecosystem Assessments* (WKEWIEA) in November 2018. Throughout the course of 2019 a follow-up workshops shall demonstrate the ability to produce quantitative ecosystem overviews in designated case studies, along with a prototype protocol for preparation of ICES key runs for the ICES Working Group on Multispecies Assessment Methods (WGSAM).

In addition, the Marine Strategy Framework Directive (MSFD; Descriptors 1 and 4) (EC, 2005a, b; 2008) mentions the urgency to develop, test and validate ecosystem state indicators. The ecosystem approach, including the assessment of food webs, is explicitly referred in the MSFD as a mean to attain a 'Good Environmental Status' (GES) of marine ecosystems. The recent revision of the Marine Strategy Framework Directive (EU, 2017) has even reinforced the importance of considering marine ecosystem structure and ecosystem functioning with the aim of attaining Good Environmental Status (GES). In its latest status paper of the biodiversity common and candidate indicators by the OSPAR convention (ICG-COBAM, 2018) the indices derived by Ecological Network Analysis (ENA) are part of one of the candidate indicators (OSPAR/FW9). Since the latest OSPAR meeting of the Intersessional Correspondence Group on the Coordination of Biodiversity and Monitoring (ICG-COBAM) in Madrid from 25th-27th November 2018, Germany (Ulrike Schückel, Nationalpark Authority Schleswig-Holstein) has taken the lead for reviving the OSPAR food web expert group. For OSPAR´s next Quality Status Report (QSR) assessment in 2023 it is planned to do case studies for inter-ecosystem comparison using ENA and to assess the impact from non-indigenous species. This work together by guidelines of the Coordinated Environmental Monitoring Programme (CEMP) is important to get ENA from candidate to an OSPAR common indicator. The Resource Management working group at ZMT has worked in fisheries research for more then two decades with a focus on small scale fisheries in tropical waters. We have made much use of the EwE software (besides using other fisheries modeling tools) to model fisheries systems in many (mainly) tropical countries (Brasil, Costa Rica, Ecuador, Colombia, Chile, Peru, Tanzania, Kenya, Ethiopia, Ghana) and the southern North Sea. Several publications (>30) came out from these models (they are listed in the reference section of this workshop report) and many of the models are part of the ECOBASE data base.

During the ENA workshop in Bremen we aimed to summarise and revisit the finding of the past workshop in Sylt (September, 2017), to present and discuss our ENA related research at ZMT and to listen to recent advances in ENA research presented by colleagues from other institutions (see objectives and workshop program below)

2. Executive Summary

During the period September 19-21, 2018 the Center for Tropical Marine research (ZMT) in Bremen organized a workshop on Ecological Network Analysis (ENA). The purpose of this meeting was to provide a forum for the Ecopath with Ecosim (EwE) and enaR science communities to present case study examples and discuss state-of-the-art approaches for Ecological Network Analysis (ENA). This workshop was the second of its kind (the first one was conducted in 2017 at the Island of Sylt, see report by Schückel et al. 2017), and was focused on tools presently used for Ecosystem modelling and Ecosystem based Fisheries Management and Conservation, but also provided examples of novel approaches for the mapping and analysis of social-ecological networks for the purposes of management and conservation. A special focus was directed towards the analysis of differences between systems (e.g. temperate vs tropical, freshwater vs marine, coastal vs offshore) in their network properties as expressed in ENA-indicators.

This workshop brought together a unique group of national and international experts in food webs, ecosystem modelling, in the implementation of EU Directives (Water Framework Directive, Marine Strategy Framework Directive, Habitat and Birds Directive, Maritime Spatial Planning) and coastal ecosystem management. An important goal was to identify and discuss appropriate food web indices derived from Ecological Network Analysis (ENA).

3. Organization

The workshop was organized and sponsored by the working group for Resource Management (WGRM) of the department Theoretical Ecology and Modeling at the Center for Tropical Marine Research (ZMT) in Bremen and lasted for three days. In charge of the workshop preparation were Moritz Stäbler, Matthias Wolff, Lotta Kluger and Elke Kasper. The workshop was part of a series of fisheries workshops conducted by the WGRM during the past 4 years. The participants were comprised of 33 experts from institutes of eight countries. 27 talks (20 minutes each) and three posters were presented during the workshop dealing with research issues related to food webs, ecological modelling, policy making and management. On the last day, a discussion was prepared in a World Café style on recent advances in social-ecological network analysis, and respective approaches and conceptual/methodological issues were presented and discussed.

Several participants left Abstracts of their presentations, which are summarised in the result section 7.

The list of the participants is attached as Annex 2.

4. Objectives of the workshop

The objectives of the workshop were:

1) to revisit findings of the last years ENA workshop on the Island of Sylt

2) to focus on fisheries applications of ENA - thereby looking at very different (mainly tropical) systems, their food webs and resource productivities.

3) to briefly look into tropical fresh water systems.

4) to see applications of a metanalysis of EwE models to explore the state of the fishery of the systems modeled and to reflect on the "Balanced Harvest "paradigm in fisheries.

5) to look into examples of time series modeling of fished ecosystems to understand the role of different drivers of system change

6) to look into examples of inter-ecosystem comparisons in response to multiple stressors

7) to look into novel approaches for the mapping and analysis of social-ecological networks for the purposes of management and conservation

8) to improve the knowledge on how sensitive ENA indices are to changes (perturbations) in the system attributable to different pressures (pressure – state change relationships) such as fisheries, invasive species, climate change, eutrophication,

9) to review the new spatial-temporal data framework of ECOSPACE that allows the implementation of annually or seasonally varying habitat capacity maps, which specifies spatial suitability in the model domain for each functional group

10) to explore how ENA results can be transferred to - and communicated with authorities and policy makers responsible for assessments and conservation issues

5. Workshop programme

Wednesday, September 19, 2018

Session I: Introduction & Context

10:00: **Matthias Wolff** Welcome to ZMT & Objectives of the workshop

10:10: **Ulrike Schückel & Victor de Jonge** Outcomes of the ENA 2017-workshop

Session II: Ecological network models for management and conservation

10:30: **Victor N. de Jonge** ‘Ecosystem based management’: nice words, but unruly to execute

10:50: **Ulrike Schückel** Assessment of mussel bed food-webs - Lessons learned from 17 years of monitoring in Schleswig Holstein

11:10-11:30 Coffee break

11:30: **Natalia Serpetti** Temporal / Spatial coupling of Ecospace: bottom-up and top-down controls – The West Coast of Scotland example

12:50: **Miriam Püts** Driving habitat capacity in Ecospace with the new spatial-temporal data framework - An example from the southern North Sea

12:10: **Moritz Stäbler** Sensitivity of multispecies MSY to trends in the top (marine mammals) and bottom (primary production) compartments of the southern North Sea food-web

12:30-14:00 Lunch break

14:00: **Nathalie Niquil** How sensitive are ENA indices to pollution? The case study of the lagoon of Bizerte, Tunisia and comparison with a multiple stress study of the Seine Bay

14:20: **Igor Eulers** Ecological networks analysis to support planning and regulating oil exploration activities and oil spill response in the Greenland Sea (presentation not given, but Abstract available, see below)

14:40: **Paul Tuda** The southern Kenyan Reef system: trophic structure and management needs

15:00: **Jennifer Rehren** Food-web & management challenges in Chwaka Bay, Tanzania

15:20-15:40 Discussion and Coffee break

15:40: -----

16:00: **Seth M. Abobi** Trophic networks of reservoir systems in Ghana

16:20: **Andrés Alegría** Ecological network modelling for assessing management scenarios in tropical artisanal fisheries, a case for Guanaja Island in Honduras

16:40-17:00 Discussion and Coffee break

17:00 Remote presentations session Ursula Scharler and Stuart Borrett Interrelation of ENA metrics how this affects their interpretation and application

20:00: Social gathering in Bremen downtown: *Ständige Vertretung*

Thursday, September 20, 2018

Session III: Social-ecological networks in management and conservation

10:00: **Marco Scotti** Qualitative assessment of human impacts on ecosystems: the case study of the Black Sea

10:20: **Theresa Schwenke & Marion Glaser** Connecting dimensions: How SENs support governance processes

10:40: **Diana Giebels** Socio-ecological network analysis: an adapted version of the net-map method to activate a social network on the regional level

11:00: **Lotta Kluger & Marco Scotti** Qualitative social-ecological network modelling for the support of ecosystem-based management

11:20-11:40 Discussion and Coffee break

Session IV Global use of Ecological Network Models

11:40: **Manuel J. Zetina-Rejón** Global topological attributes of marine foodwebs

12:00: **Manuel J. Zetina-Rejón** Using social network analysis for analysing the role of stakeholders in fisheries: Lessons from two fisheries at the Northwest Mexico

12:20: **Jeppe Kolding** How “balanced” are current fisheries? A meta-analysis of global Ecopath models

12:40-14:10 Lunch break

Session V: Comparing food-webs geographically

14:10: **Matthias Wolff** Comparing mangrove food-webs and resource productivities

14:50: **Harald Asmus** The food-web of the Wadden Sea in a warmer world – a case study of the Sylt-Rømø Bight

15:10 -16:00 Discussion and Coffee break**Open session**

16:00: **Parallel working group sessions** Future collaborative projects, Next steps for ENA, Planning of next ENA-workshop

Friday, September 21, 2018

Session VI: Time series analysis for Food-web models

10:00: **Pierre Olivier** When more diversity means less complexity: A study of topology in dynamic food-web

10:20: **Marc Taylor** Drivers of change of the Humboldt Current ecosystem (Peru)

10:40: **Matthias Wolff** Looking at El Nino impacts on the Bolivar Channel ecosystem (Galapagos)

11:00-12:30 Poster session

Maike Scheffold Towards evaluating the potential of marine biological carbon management

Jacob Bentley Incorporating Fisher’s Knowledge and Uncertainty Analyses into the Development of Ecosystem Models

Emma Araignous Spatialization of ENA indicators: a new plug-in for Ecospace

12:30-14:00: Farewell lunch at Z

Session VII: The network approach for modelling social-ecological systems

14:00: **Lotta Kluger, Marco Scotti & Manuel Zetina** invite you to an open World Café style discussion on recent advances in social-ecological network analysis, respective approaches and conceptual/methodological

6. Central questions and expected outcomes of workshop

Application level of ENA approaches for management

Ecological Network Analysis (ENA) allows to holistically analyse the structure and functioning of any terrestrial and aquatic ecosystem and is therefore suitable as the basis for any ecosystem-based approach in management. ENA contains a set of algorithms that allow to evaluate the trophic flows and cycling of material through ecosystems from which a set of system indices can be derived to describe the overall ecosystem (e.g. Ulanowicz, 1986, 2004).

Despite the clear indications of a possible coupling between (Drivers) - Pressures-State change (ecological as well as societal) and – Impacts - (Responses) up to now, ENA indices are by OSPAR only accepted as “surveillance indicators”[1] Closing the knowledge gaps, such as pressure/state change relationships or missing thresholds, it is necessary to show administrative institutions like ICES or OSPAR the potential of the ENA approach (but see the above comments on the EwE role for ICES fisheries management and ongoing work of OSPAR food web expert group). Once this step is achieved, a full operationalization of the application of ENA indices for assessment and management purposes is possible.

Questions of relevance for ongoing ENA research

- What are the current research needs on our global agendas with regard to the assessment of food web structure and ecosystem resilience?
- What indices or set of indices are most suitable to assess the status of food webs?
- How suitable are the proposed ecosystem health ENA indices by Fath et al. (submitted, ENA Workshop 2017) to assess the ecosystem state?
- To test how different or similar theses ENA indices react to changes and how sensitive they are to different stressors?
- Are there any general patterns in the reaction to the same stressor e.g. eutrophication, temperature to define pressure/state change relationships ?
- What data is needed to assess the status and trends of food webs, to be implemented into national and/or international monitoring programs?
- How can we improve our knowledge about uncertainty in the estimation of ENA indices (dealing with trends which are not always in the same direction)
- How to improve the enaR and EwE packages and make them from a technical point of view more applicable and user-friendly for managers and civil servants ?

Expected outcomes of the workshop

- Insight into similarities and differences between responses/outcomes of ENA indicators/metrics in different case studies worldwide
- Common set of ENA indices that would be applicable across sub(OSPAR)regions
- Insight into monitoring programs and directives abroad
- Roadmap for future steps dealing with: i) technical aspects, ii) scientific bases and standardization (protocols) and ii) application and assessment
- Need to develop a coordinated protocol on how to construct food webs with respect to different software tools (enaR, ECOPATH) to achieve comparable results
- To get insights and to establish a roadmap how to transfer and communicate results from science to management
- Transfer of Workshop results and key recommendations into OSPAR Food web expert group as well as national groups

7. Results

In this section, some of the main results and conclusions are presented that emerged from the presentations of Sessions I-VII

Session I: Introduction & Context

Matthias Wolff Welcome to ZMT & Objectives of the workshop

Dear colleagues & friends,

Almost exactly a year ago we met at the AWI Wattenmeerstation in List on the island of Sylt for the past ENA workshop that was entitled „Use of coastal and estuarine food web models in politics and management: The need for an entire ecosystem approach".Ulrike Schückel & Victor de Jonge will be so kind and give a summary of the outcome of this workshop just in a few minutes. So, I will not go further into this here. I enjoyed the workshop very much and recognized (what I had not known before - please excuse my ignorance!) that there was a strong group working in ENA using R as their programming language. Stuart Borrett presented the enaR package and explained its features. Last week he had send around their recently published review paper on Ecological Network Analysis which is a fantastic summary of what has been done by whom in the field and where. In the paper he shows a map (see Introduction), which is just great and may motivate you to further read the paper.

I recognized, while reading through the paper that our group`s work is not mentioned---and understood that this is a reflection of the fact that the key words that were used for this review are not the ones usually given in our publications: They used the terms "Ecological Network Analysis,"Network Environ Analysis," and "Ecosystem Network Analysis." In our papers we rather use terms such as "flow structure" or food web models or Trophic flow models". So, this made it again clear to me how important it is to use a common terminology if one wants to belong to the ENA community.

While much of what we were doing during the last years`s workshop we shall revisit during the next 3 days, we shall focus in this workshop a bit more on fisheries applications of ENA (because this is what we are doing in our working group) - thereby looking at very different (mainly tropical) systems, their food webs and resource productivities. We also shall briefly look into tropical fresh water systems. I had hoped that Gashaw Tesfaye, a former member of our working group from Ethiopia could join our workshop to present his great work on the lake Koka model, which was just published in Ecological Modelling (see reference section), but he could not make it to the workshop - a great pity. Seth Abobi from Ghana, who is also going to present his work on freshwater systems, shall be so kind to briefly summarise Gashaws work, when he is speaking this afternoon. I should also mention that Regina Bacalso another member of our working group from the Philippines working on fishing effort reallocation problems (one of her papers is also given in the reference section), could not make it to our workshop. In the first version of the program both had still been included.

We shall see from a metanalysis done by Jeppe Kolding - by using trophic EwE models of fished ecosystems – how far or close these systems are to a balanced fishing regime. We shall also focus on examples of time series modelling of fished ecosystems to understand the role of different drivers of system change.

A further focus of our workshop is on novel approaches for the mapping and analysis of social-ecological networks for the purposes of management and conservation

This time we shall also have two remote presentations by Ursula Scharler and Stuart Borret at 17:00 in the afternoon. We very much hope that this will work out

Session II: Ecological network models for management and conservation

Victor N. de Jonge 'Ecosystem based management': nice words, but unruly to execute

To better manage the interaction between human activities and the environment, all sorts of European Directives were enacted with that one big idea on how to protect and improve the quality of the ecological 'structure' and its 'functioning' (Water Framework Directive/ WFD, article 2, paragraph 21 and the Marine Strategy Framework Directive/ MSFD descriptors 1 (biodiversity) and 4 (food webs). Since the introduction of the WFD in 2000 many well-sounding and appealing terms, acronyms and diagrams were created to support the spirit of these directives. An unambiguous assessment of our ecosystems that represent our living environment has, however, so far not been presented. It seems that there is a solution for this unruly problem and that is the application of Ecological Network Analysis (ENA) to assess the 'functioning' of ecosystems in combination with assessing the ecosystems biodiversity. It moreover emerges that ENA can not only be applied to assess ecosystem characteristics, it can also be used to explore system changes under the influence of human activities

Ulrike Schückel Assessment of mussel bed food-webs - Lessons learned from 17 years of monitoring in Schleswig Holstein

The Marine Strategy Framework Directive (MSFD) stresses the urgently need of development of indicators that relate to food web functioning and dynamics (Descriptor 4), which can effectively be used for policy making and management at the national as well as the EU level. The Ecological Network Analysis (ENA) is a holistic approach to assess the status of marine habitats and ecosystems by analyzing the food web structure, functioning and system properties. In the present study, we investigated temporal dynamics of food web models based on long term monitoring data of mussel beds and associated benthic fauna part of the Trilateral Monitoring and Assessment Program (TMAP) since 1999. Results of temporal changes for highly invaded mussel beds by the Pacific oyster and a non-invaded mussel bed over time are presented. Special emphasis is put on different food web indices and attributes, which are proposed to be potential indicators to evaluate the status of food webs. In context of determining the „good ecological status" of coastal ecosystems, in a first approach specific reference values necessary for the assessment according to demands of the MSFD were developed.

Natalia Serpetti Temporal / Spatial coupling of Ecospace: bottom-up and top-down controls – The West Coast of Scotland example

Miriam Püts Driving habitat capacity in Ecospace with the new spatial-temporal data framework - An example from the southern North Sea

Moritz Stäbler Sensitivity of multispecies MSY to trends in the top (marine mammals) and bottom (primary production) compartments of the southern North Sea food-web

Various spatial drivers within the Ecospace models can drive the spatial allocation of functional group biomass. The influence of environmental parameters on the biomass distribution of functional groups can be defined via habitat foraging or with the use of environmental responses. The new spatial-temporal data framework however allows the implementation of annually or seasonally varying habitat capacity maps, which specifies spatial suitability in the model domain for each functional group. In this study, this framework was applied to a wide range of functional groups in an Ecospace model created for the southern North Sea. Habitat capacity maps were build using the binomial predictions from hurdle Generalized Additive Models (GAMs) fit to surveyed biomass data (1991-2016) as a function of space and season, year (i.e. stock size changes), and temperature. Predicted biomass distributions of the full hurdle GAM were used to assess the performance of Ecospace in reproducing historical distribution patterns. The study illustrates the potential of the spatial-temporal data framework of Ecospace as well as provides a practical protocol for its use and evaluation.

Food-web modelling of the west coast of Scottland and the southern North Sea is undertaken in support of the Ecosystem Approach to Fisheries Management. Modellers use the Ecosim and Ecospace features within the Ecopath with Ecosim software and modelling approach. They test the feasibility of good multispecies fishing yields under consideration of food-web structure and functioning, and explore how these fishing options are altered by projected anthropogenic changes of the ecosystem, such as ocean warming, recovering stocks of marine mammals, de-eutrophication measures and marine spatial planning. While these approaches are primarily scoped towards fisheries management in terms of yields, ENAs bear relevance as indicators of the European Commission's Marine Framework Directive.

Nathalie Niquil How sensitive are ENA indices to pollution? The case study of the lagoon of Bizerte, Tunisia and comparison with a multiple stress study of the Seine Bay

The seasonal variability of feeding interactions within the planktonic food web was investigated in coastal waters of the southwest Mediterranean. Plankton biomass, bacterial and algal production, as well as grazing impact of both microzooplankton and mesozooplankton were assessed at inshore (Lagoon and Channel of Bizerte) and offshore stations (Bay of Bizerte). These data were a basis for building plankton models of these different situations in seasons and locations, and also in pollution loads and eutrophication. Those models could then be used to project the consequence of this stress on the food web functioning. Linear inverse analysis was applied, using the Monte Carlo method coupled with Markov Chains, to estimate flow values and Ecological network analysis was used for the description of structural and functional properties of each food web and for inter-ecosystem comparisons. Then, the same association of numerical tools was applied in an experimental situation characterising a situation of sediment resuspension, with the associated release into water column of a complex mixture of contaminants and nutrients. All these situations were compared to characterize the sensitivity of ENA indices to stress and the results were linked to different ecological theories on maturity and ecological functioning.

Igor Eulaers Ecological network analysis to support planning and regulating oil exploration activities and oil spill response in the Greenland Sea

With increasing oil exploration activities in the Greenland Sea more information on the ecology and temporal and spatial sensitivity of this very little studied marine ecosystem is urgently needed for environmental planning and regulation of oil exploration activities and oil spill response. We present our ongoing investigation of the potential of ecological network analysis to improve current practices in environmental impact assessment. Our first strategy aims at expanding the current definition of the species-specific oil spill impact value, which is at the present day solely based on oil exposure sensitivity and species abundance, by adding species-specific food web ecological metrics. Our second strategy aims at improving the oil spill impact value of the overall ecosystem, which is currently simply the summation of the species-specific impact values but does not take into account the food web ecological interactions among species. Our network analytical analysis incorporates both theoretical simulation exercises as well as modelling of spatiotemporal variation in the weighted network based on empirical biogeochemical data.

Paul Tuda The southern Kenyan Reef system: trophic structure and management needs

The network analysis routine in Ecopath was used to characterise in terms of flows and assess the ecological impacts of fishing on the Gazi Bay ecosystem, a semi-enclosed and shallow tropical coastal system located in the Kenyan South Coast. The system was partitioned into 23 functional groups consisting of ten fish groups and eleven aggregated groups of species including the detritus. To allow for comparison to other tropical marine ecosystems, system properties commonly used to describe changes in ecosystem properties were computed. The mixed trophic impact analysis was used to assess the impacts of fishing and quantify the direct and indirect impact of each gear on the functional groups. Results indicate that the Gazi Bay ecosystem is characterised by bottom-up control with herbivory dominating energy flow to higher trophic levels. The analyses of ecosystem maturity suggested that Gazi Bay is in a development stage towards maturity given the high system production to biomass ratio (P_p/B) relatively high primary production to respiration ratio (P_p/R), and low system biomass to system throughput ratio (B/T).
Further, the low Finn's Cycling Index, connectance index (CI) and the system omnivory index (SOI) were suggestive of a system that is not entirely mature and stable. Thus, the system is most likely negatively impacted by fishing based on the high computed exploitation rates of key resources (F/Z >0.5). The results of the mixed trophic impact analysis revealed that fishing impact on the target species varied between gears but the fishing gears impacted negatively on each other likely due to the spatial overlap and competition between gears for similar target species. This preliminary analysis of the Gazi bay ecosystem presented the possibilities of applying network analysis to analyse the trophic structure and to assess the ecosystem impacts of fishing unlike traditional single-species assessment, which tends to focus only on the exploited species. Thus it provides a pathway for incorporating ecosystem-based management to a tropical data limited fishery.

Jennifer Rehren Food-web & management challenges in Chwaka Bay, Tanzania

The use and spatio-temporal overlap of multiple gears in Chwaka Bay (Zanzibar) has led to severe conflicts between fishermen. There is a general concern of overfishing in the bay because of the widespread use of small mesh sizes and destructive gears such as dragnets and spear guns. We constructed an *Ecopath* food web model to describe the current trophic flow structure and fishing pattern of the bay. Based on this model, we explored the impact of different gears on the ecosystem and the fishing community in order to give advice for gear based management in the bay. Results indicate that Chwaka bay is a productive, shallow water system, with biomass concentrations around the first and second trophic level. The system is greatly bottom-up driven and dominated by primary producers and invertebrates. The trophic and network indicators as well as the community energetics characterize Chwaka Bay as relatively mature. Traps and dragnets have the strongest impact on the ecosystem and on the catches obtained by other gears. Both gears potentially destabilize the ecosystem by reducing the biomass of top-down controlling key species (including important herbivores of macroalgae). The dragnet fishery is the least profitable, but provides most jobs for the fishing community. Thus, a complete ban of dragnets in the bay would require the provision of alternative livelihoods. Due to the low resource biomass of fish in the bay and the indication of a loss of structural control of certain fish groups, Chwaka Bay does not seem to provide scope for further expansion of the fishery. Instead, we recommend an effort control of traps and a reduction in the use of dragnets, partially by redistributing them to the more profitable and less impacting gears (e.g. longlines, gillnets, handlines).

Seth M. Abobi Trophic networks of reservoir systems in Ghana

The objective of the study is to assess and compare food web structure, biodiversity and fisheries productivity of Golinga, Bontanga and Tono reservoir ecosystems in Ghana as related to their different features. One of the main research questions is to determine the physical features of the reservoirs that drive differences in food web structure and resource productivities.Expected findings of the ongoing study are: (1) Minimal differences in functional groups composition is expected among the reservoirs;(2)It is expected that there will be no significant difference in the level of development and organization between the old and the young reservoir systems, due to relatively short age differences (12 years) between the reservoirs; (3)Differences in the reservoirs physical features (shape, mean depth, overall size, and water holding capacity) will relate to their differences in food web structures and resource productivities; (4)The smallest (Golinga) reservoir will be the most unstable system when siltation (reduction in reservoir depth) is used as a forcing function for spatial-temporal simulation.

Andrés Alegría Ecological network modelling for assessing management scenarios in tropical artisanal fisheries, a case for Guanaja Island in Honduras

A mass-balance trophic model was constructed using Ecopath to describe the ecological structure, the trophic dynamics, and the economic value of the marine resources associated with the coral reefs surrounding Guanaja, a tropical island in the Caribbean located off the north coast of Honduras. Here, the livelihood of about 400 fishermen and their families rely on fisheries. In response to increasing concerns about the sustainability of these resources and to the opportunities for investing in management strategies as identified by local fishermen and municipal authorities, through this model, temporal simulations fitted to time series where used to assess the viability of management actions including the enforcement of no-take zones, and the establishment of artificial reefs as a means to enhance local artisanal fishery of Caribbean spiny lobster, which is one of the most valuable fishing resource in the region.

Session III: Social-ecological networks in management and conservation

Marco Scotti Qualitative assessment of human impacts on ecosystems: the case study of the Black Sea

Starting from 1950s the Black Sea ecosystem has undergone a series of human induced impacts, which include overfishing, excess nutrient load and species invasion. Such impacts shifted energy circulation from the plankton-dominated grazing chain to the jellyfish and the microbial loop. The complex interplay between the impacts and the architecture of trophic interactions make it difficult to disentangle the cause-effect mechanisms behind the regime shift.Therefore, we applied loop analysis to identify the subset of anthropic impacts and interactions that caused the biomass changes in the Black Sea. First, nutrient enrichment played a key role to counterbalance the impacts of overfishing during the 1960s and the 1970s, thus delaying the decline of planktivorous fish. Second, warmer winter temperatures and overfishing were crucial for the marked increase of *Mnemiopsis leidyi* in the years 1989-1994. The model also illustrated the relevance of *M. leidyi* predation on planktivorous fish larvae to justify the jellyfish bloom in presence of eutrophication. Our work shows the value of loop analysis for the integrated understanding of system-level dynamics. We suggest that loop analysis represents an ideal tool to develop models that effectively combine variables belonging to both ecological and social domains.

Theresa Schwenke & Marion Glaser Connecting dimensions: How SENs support governance processes

Diana Giebels Socio-ecological network analysis: an adapted version of the net-map method to activate a social network on the regional level

Socio-ecological network analysis is an important tool to understand human-nature interactions. However, it can also be used to map and potentially activate social networks fostering ecosystem-based management. This paper reports about an experiment, using an adapted version of the network method called 'net-map'. The experiment was conducted with 21 participants stemming from 12 different organisations. Intention of the experiment was to explore and potentially activate a social network on the regional level (Lower Saxony, Germany). The method helps to understand how individual network members visualize network structure and functioning. Furthermore the method has shown its usefulness for mapping and comparing potential roadmaps for future collaboration and to identify network problems caused by non-existing network ties.

Lotta Kluger & Marco Scotti Qualitative social-ecological network modelling for the support of ecosystem-based management

Coastal marine resources provide livelihoods to human communities around the world. The interactions in coastal marine social-ecological systems are usually of complex nature, due to a wide range of different fisheries interacting with the food web. Understanding connectivity and biomass flows within these systems helps in establishing meaningful management strategies for long-term sustainable use of marine resources. This work uses the value chain analysis of different fisheries sectors to construct a qualitative social-ecological network model of the Sechura Bay in North Peru. Here, a diverse ensemble of small-scale fisheries co-exists with a flourishing mariculture sector, though the respective production chains partially overlap. Results of the network analysis suggest position of nodes being related to their vulnerability in the face of external disturbances. Besides being relevant to the study system, results of this work will nourish on-going discussion on the use of social-ecological network analysis to describe human-nature interactions.

Session IV Global use of Ecological Network Models

Manuel J. Zetina-Rejón Global topological attributes of marine foodwebs

Manuel J. Zetina-Rejón Using social network analysis for analysing the role of stakeholders in fisheries: Lessons from two fisheries at the Northwest Mexico

Jeppe Kolding How "balanced" are current fisheries? A meta-analysis of global Ecopath models

A global assessment of fishing patterns and fishing pressure from 129 global marine and 13 inland African Ecopath models, representing a large diversity of marine and freshwater ecosystems, show that human exploitation across trophic levels is highly unbalanced and skewed towards low productive species at high trophic levels, which are around two trophic levels higher than the animal protein we get from farming. Overall the global exploitation levels from low trophic species was less than 15% of production, and only 18% of the total number of exploited groups and species were harvested above 40% of their production. Generally, well-managed fisheries from temperate ecosystem were more selectively harvested than tropical and upwelling fisheries, resulting in potentially bigger long-term changes to the ecosystem structure and functioning. The results indicate a very inefficient utilisation of the aquatic production. Global fisheries have the potential to provide significantly increasing overall catches while rebuilding overfished components, if the current fishing regimes were changed towards fishing that is more balanced among trophic components of the ecosystems

Session V: Comparing food-webs geographically

Matthias Wolff Comparing mangrove food-webs and resource productivities (summary):

Mangroves systems of similar mangrove coverage may differ in resource productivity by an order of magnitude- so mangrove coverage as a single factor is not suitable as predictor for resource productivity. The biophysical settings of mangroves (from strongly riverine influenced to oceanic, from arid to very humid, from small to large tidal ranges, from daily flushing to flushing only each fortnight, etc.) are greatly influencial for the food web structure and resource productivity. Human pressure on mangroves and its resources is often strongly related to human population density around the mangrove areas as well as to the proximity to local and regional markets for mangrove products. According to the above, the value of mangroves in terms of their provisioning services may greatly vary from site to site and region to region. However, in most countries of important mangrove coverage, a very significant part of the fisheries resources are derived from mangrove areas

Harald Asmus The food-web of the Wadden Sea in a warmer world – a case study of the Sylt-Rømø Bight

Session VI: Time series analysis for Food-web models

Pierre Olivier When more diversity means less complexity: A study of topology in dynamic food-web (authors: Pierre Olivier, Romain Frelat, Erik Bonsdorff, Jens Floeter, Mira Grönblom, Susanne Kortsch, Ingrid Kröncke, Christian Möllmann, Hermann Neumann, Margarethe Nowicki, Anne F. Sell, Marie Nordström) Ecological network analysis is traditionally divided by trade-offs between complexity, in terms of size of the network, and dynamics. Topological analysis uses complex food webs (with a high number of species and links) but is limited to a static view, while ecosystem models can be dynamic but use simplified food webs (with highly aggregated trophospecies). In our study, we present a novel method to perform topological analysis of food web structure through time. We combined commonly used topological indicators with time series of species' abundances; this way, we were able to investigate how temporal changes in species composition alter food web structure. As a case study, we used long-term monitoring ecosystem surveys of fish and epifauna communities from the German Bight. We constructed a topological food web, including 27 fish and 24 epifauna species, based on information on feeding links. Our results revealed that connectance, a proxy for the complexity of the community, has an inverse relationship with species richness. Our case study demonstrates the application of a novel methodology that can provide new insights about the dynamics and the complex structure of biotic communities, information important for the management and conservation of ecosystems.

Marc Taylor Drivers of change of the Humboldt Current ecosystem (Peru)

The coastal upwelling system of the northern Humboldt Current ecosystem (NHCE) is considered the most productive in the world in terms of fish production, due mainly to the catches of small pelagics such as anchovy and sardine. Large fluctuations in the landings of these and other important resources have been attributed to both fishing and natural variability from the El Niño Southern Oscillation (ENSO). Using trophodynamic models (Ecopath with Ecosim), the work explores the relative importance of fishing, environmental, and trophic drivers to historical dynamics. Fishing was found to be a significant driver throughout the period of study (1996-2003) while ENSO changes to primary production were mainly responsible for shorter-term variability following the strong El Niño event of 1997-98. The findings also emphasize the need that future work should place further emphasis on spatial dynamics in order to better account for important trophic linkages occurring between the main upwelling and offshore habitats.

Matthias Wolff Looking at El Nino impacts on the Bolivar Channel ecosystem (Galapagos)

El Niño induced reduction in Phytoplankton and Macroalgae cascades through all trophic levels. System biomass as well as energy throughput are reduced to about half during the El Niño (similar to what was reported for the Peruvian upwelling system), which explains why catches were also reduced by 62.2%. System size (for non El Niño years) of almost 30 000 t km^{-2} $year^{-1}$ exceeds that of most tropical systems of the East Pacific Seascape Region and elsewhere. Besides great functional similarities with upwelling systems of the SE Pacific, the BCE has many unique features: an enormous diversity and biomass of fish species of different habitats (open water, rocky reef, sand bottom) and trophic guilds (predators, detrivors, planktivors, omnivors, large biomasses of non bivalve filter feeders such as gorgonians, zoothanthids, sponges and endemic ahermatypic corals (*Tubastraea faulkneri* and *T. tagusensis*) (whereas bivalve filter feeders use to dominate the shallow upwelling systems along the South East Pacific shore). An interesting feature of the BCE is the lack of large cangrid or xanthid crabs, well known benthic predators of the South East Pacific. Their niche seems to be occupied by three species of Spiny lobsters (*Panulirus penicillatus*, *P.*

gracilis, and *P. femoristruga*) and one species of Slipper lobster (*Scyllaride astori*). The proportion of endemic species is high in the BCE and exceeds the level of endemism in the north-western and south-western regions of Isabela and of western Fernandina. For this reason, and because several invertebrates species have only been recorded here, the BBCE area is considered unique for its mix of tropical and temperate species.

Session VII (workshop): The network approach for modelling social-ecological systems

Kluger, Zetina, Scotti (*summary*)

Social-ecological network analysis (SENA) is an emerging field that aims at studying complex interactions involving social actors (e.g. institutions, stakeholders) and ecosystems (e.g. species, ecological processes). Theoretically, the concept provides a basis to advance the modelling of players from both the social and the ecological realm as to enhance ecosystem conservation and sustainable resource management. In practice, however, the identification of actors (nodes) and interactions (links) as well as the definition of system boundaries are case-specific and often difficult to operationalize. The lack of unambiguous rules for model construction and social-ecological network analysis hampers the development of uniform, transferrable approaches. Session VII intended to bring together all (workshop) participants working on or being interested in SENA. Goals of the session were (1) to focus on the theoretical framework for the use of network analysis to model social-ecological systems; (2) to identify the currently used methods and suggest possible future developments; and (3) to summarize data requirements and suitable sampling strategies.

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8.Take Home messages

During the plenary discussion on the last workshop day the following take home messages were formulated and noted

- Ecosystem based management sounds nice but is difficult to execute for the reasons that terminology is not standardized, and because system indicators are often only meaningful, if a closer look is done on the compartment/node level (Victor de Jonge)

- Some work suggests that system biomass as well as Relative Overhead may be simple and meaningful indicators of system state (Victor de Jonge)

- Long-term series and monitoring data are essential to study the impact of stressors on ENA indices. ENA indices of an Pacific oyster invaded blue mussel bed food web are influenced by the temporal variability in biomass of the Pacific oyster or parameters that were influenced by the oyster such as the size of the bank. The state of a natural blue mussel bed food web is influenced by natural stressors such as cold winters (Ulrike Schückel).

- Whenever possible use different spatially-coupled models and allow them to talk to each other)- this is however often quite difficult. (Natalia Serpetti, West Coast Scotland example)

- Driving habitat capacity in Ecospace with the new spatial-temporal data framework is a great approach – (Miriam Püts, Southern North Sea example)

- Explorations of the Sensitivity of multispecies MSY to trends in the top (marine mammals) and bottom (primary production) compartments of the southern North Sea food-web demonstrate the potential benefits from incorporating food web level interactions and trends into long-term stock and ecosystem level management. It shows that, in the southern North Sea, this is particularly the case for bottom-up processes (Moritz Stäbler).

- To test the sensitivity of ENA indices to pollution, mesocosm experiments should be used more frequently These could also be helpful to better understand under what conditions the Finns Cycling Index (FCI) and Ascendency/Capacity (A/C) ratio change (Natalia Niquil).

- The exploitation rates of target resources estimated by EwE models may differ from estimates from single species assessment, due to scale effects and or due to not enough consideration of natural losses in the single species assessment. (Paul Tuda)

- The decrease in the Mean Trophic Level of the catch (MTLC) as indicator of fishing state needs to be used with caution, because different processes may lead to its change, such as a simple switch of the fishery from high to low trophic level species (Matthias Wolff)

- For coastal ecosystems, the microbial activity needs to be taken into account for energy based network models; it only makes sense to compare systems which have or have not the microbial loop considered

- Fully exploited tropical systems (like Chwaka Bay, Zanzibar) with strong overuse of dragnet, may allow for some reallocation of fishermen to different, less harmful, gears. EwE models are good tools for exploring the ecological, social and economic impact of this reallocation of fishing effort (Jennifer Rehren)

- For simple assessment approaches in small scale tropical fisheries use size and numbers not kg (Jeppe Kolding)

- Tropical Freshwater systems may differ in resource productivity although looking similar. Not yet totally clear what the drivers are for resource productivity of reservoir systems (Seth Abobi)

- Ecosystem indices should only be used for the characterization of the ecosystem if a closer look at the topology of the models and the comprising nodes is done. If not, contradicting results may show up. MTL does seem a good indicator for system health (Ursula Scharler and Stuart Borrett)

- ENA approaches are very diverse and a strong use is in Urban metabolism. ENAr /Pattern and Ulanowicz indices may be complementary (Ursula Scharler and Stuart Borrett)

- Loop analysis can be a nice tool to explore different system configurations/scenarios of impacts- more ”democratic approach” since all nodes and interactions are of same relevance. Combine/overlay results of models (Marco Scotti)

- Stakeholder mapping is an important and needed first step to understand the complexity of SES (Theresa Schwenke & Marion Glaser**)**

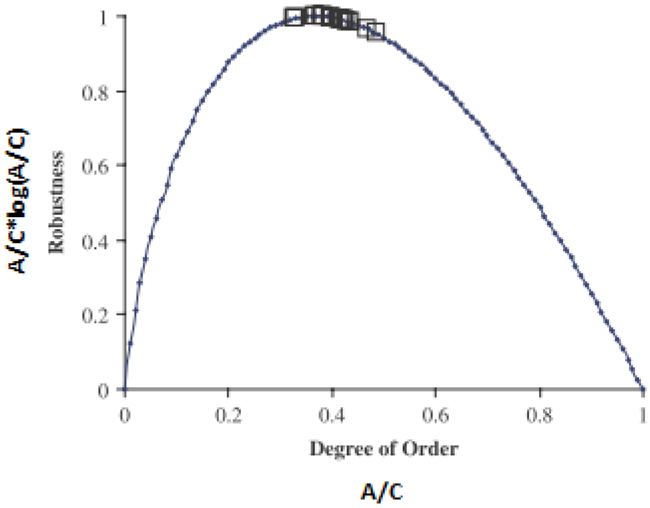
- The SEN approach seemed to be very useful to highlight difference in fisheries SES especially with regard to dependencies and vulnerabilities of stakeholders (Manuel Zetina, Lotta Kluger)

- EwE Models are remarkably similar in many of their topological features, which opens the question of the why: possibly the fact that all models/systems are constraint by the need to balance production and consumption and by the fact that compartments need to obey physiological rules (P/Q, Q/B ratios for example) may make systems to resemble each other. Compare what can be compared-among system comparison is difficult (Manuel Zetina)

- EwE models can be used to understand fishing patterns /how and how much?
  But how can I use ENA results in fishing assessment work?- they still seem too complex for practical fisheries applications (Jeppe Kolding)

- There are several ENA (EwE) time series models that have explored environmental impacts on the stucture and functioning of aquatic systems and that have allowed to differentiate between the impact of different drivers on the fished ecosystem and to better understand the control mechanisms in food webs (Matthias Wolff, Marc Taylor)

- As a system robustness indicator, the relative Ascendency/Capacity ratio (Ulanowicz, 2009, see Fig. below) seems to work well and comparative studies suggest that a value outside the range from 0.3-0.5, is most likely indicative fro strong system disturbance



The degrees of order and corresponding magnitudes of robustness (Ulanowicz 2009) Squares represent a subset of 17 ecosystem flow networks used by Zorach and Ulanowicz (2003).

9. Annexes

Annex 2 List of participants

ANNEX 1 LIST OF PARTICIPANTS

Family name	*Given name*	*Affiliation*	*Country of affiliation*
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Wolff	Matthias	Leibniz Centre for Marine Tropical Research (ZMT)	GER
Zetina-Rejón	Manuel	National Polytechnic Institute, Mexico	MEX

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