1. **Plenty More Fish in the Sea?**

R. A. Watson, T. J. Pitcher, S. Jennings, (2017). *Fish and Fisheries* 18, 105-113.

Conservation, global abundance, historical fishing, reconstruction, stock assessment

10.1111/faf.12128, http://www.ecomarres.com/downloads/FishinSea.pdf

Only in the last century did humans overwhelmingly accept that fisheries resources are finite. Consequently, ‘there are more fish still in the sea than ever came out of it’ served as a popular metaphor for unbounded expectations for half a millennium, expectations that also extended to use of the planet in general. By reconstructing historical fishing back 1200 years, we identify when this metaphor actually ceased to be true. For some of our most important stocks, it has not been true for centuries, although surprisingly, for fishes globally, it applied until the last century. We demonstrate, however, that there can still be ‘plenty more fish in the sea’ and that with effective management they provide a continuous flow of benefits for our future.

2. **Global Seafood Trade Flows and Developing Economies: Insights from Linking Trade to Production.**

R. A. Watson, R. Nichols, V. W. Y. Lam, U. R. Sumaila, (2017). *Marine Policy* 82, 41-49.

global seafood trade; global fisheries; seafood value; developing nations; access agreements

, http://www.ecomarres.com/downloads/Trade2.pdf

Knowing the patterns of marine resource exploitation and seafood trade may help countries to design their future strategic plans and development policies. To fully understand these patterns, it is necessary to identify where the benefits accumulate, how balanced the arrangements are, and how the pattern is evolving over time. Here the flow of global seafood was traced from locations of capture or production to their countries of consumption using novel approaches and databases. Results indicate an increasing dominance of Asian fleets by the volume of catch from the 1950s to the 2010s, including fishing in the high seas. The majority of landings were by high-income countries’ fishing fleets in their own waters in the 1950s but this pattern was greatly altered by the 2010s, with more equality in landings volume and value by fleets representing different income levels. Results also show that the higher the income of a country, the more valuable seafood it imports compared to its exports and vice versa. In theory, this implies that the lower income countries are exporting high value seafood in part to achieve the broader goal of ending poverty, while achieving the food security goal by retaining and importing lower value seafood. In the context of access arrangements between developed and developing countries, the results allow insights into the consequences of these shifting sources of income may have for goals such as poverty reduction and food security.

3. **A Database of Global Marine Commercial, Small-Scale, Illegal and Unreported Fisheries Catch 1950-2014.**

R. Watson, (2017). *Nature Scientific Data* 4,

10.1038/sdata.2017.39, http://www.ecomarres.com/downloads/scidata.pdf

Global fisheries landings data from a range of public sources was harmonised and mapped to 30-min spatial cells based on the distribution of the reported taxa and the fishing fleets involved. This data was extended to include the associated fishing gear used, as well as estimates of illegal, unregulated and unreported catch (IUU) and discards at sea. Expressed as catch rates, these results also separated small-scale fisheries from other fishing operations. The dataset covers 1950 to 2014 inclusive. Mapped catch allows study of the impacts of fisheries on habitats and fauna, on overlap with the diets of marine birds and mammals, and on the related use of fuels and release of greenhouse gases. The fine-scale spatial data can be aggregated to the exclusive economic zone claims of countries and will allow study of the value of landed marine products to their economies and food security, and to those of their trading partners.

4. **Reconciling Fisheries Catch and Ocean Productivity**

C. A. Stock, J. G. John, R. R. Rykaczewski, R. G. Asch, W. W. L. Cheung, J. P. Dunne, K. D. Friedland, V. W. Y. Lam, J. L. Sarmiento, R. A. Watson, (2017). *PNAS* 114, E1441-E1449.

10.1073/pnas.1610238114, http://www.ecomarres.com/downloads/CatchProduction.pdf

Photosynthesis fuels marine food webs, yet differences in fish catch across globally distributed marine ecosystems far exceed differences in net primary production (NPP). We consider the hypothesis that ecosystem-level variations in pelagic and benthic energy flows from phytoplankton to fish, trophic transfer efficiencies, and fishing effort can quantitatively reconcile this contrast in an energetically consistent manner. To test this hypothesis, we enlist global fish catch data that include previously neglected contributions from small-scale fisheries, a synthesis of global fishing effort, and plankton food web energy flux estimates from a prototype high-resolution global earth system model (ESM). After removing a small number of lightly fished ecosystems, stark interregional differences in fish catch per unit area can be explained ($r = 0.79$) with an energy-based model that (i) considers dynamic interregional differences in benthic and pelagic energy pathways connecting phytoplankton and fish, (ii) depresses trophic transfer efficiencies in the tropics and, less critically, (iii) associates elevated trophic transfer efficiencies with benthic-predominant systems. Model catch estimates are generally within a factor of 2 of values spanning two orders of magnitude. Climate change projections show that the same macroecological patterns explaining dramatic regional catch differences in the contemporary ocean amplify catch trends, producing changes that may exceed 50% in some regions by the end of the 21st century under high emissions scenarios. Models failing to resolve these trophodynamic patterns may significantly underestimate regional fisheries catch trends and hinder adaptation to climate change.

5. **Drivers of Fuel Use in Rock Lobster Fisheries**

R. Parker, C. Gardner, B. S. Green, K. Hartmann, R. A. Watson, (2017). *ICES Journal of Marine Science*,

energy, fisheries, fuel, greenhouse gas emissions, lobster.

10.1093/icesjms/fsx024, http://www.ecomarres.com/downloads/lobsterfuel.pdf

Fuel consumption is a leading cost to fishers and the primary source of greenhouse gas emissions from the global fishing industry. Fuel performance varies substantially between and within fisheries, but the drivers behind this variation are unclear and inconsistent across studies. We surveyed rock lobster fishers in Australia and New Zealand to measure rates of fuel use and assess the influence of technological (e.g. vessel size, engine power), behavioural (e.g. distance travelled, speed), and managerial (e.g. catch per unit effort, fishery capacity) factors. Weighted fuel use intensity across the region was 1,890 l/t. Managerial factors were the most influential drivers of fuel use in single day trips while technological factors heavily influenced multi-day trips. Catch per unit effort was the only significant driver present across both types of fishing trips. The vast majority of surveyed fishers identified fuel use as an important aspect of fishing operations, and nearly half had already implemented changes to try to reduce consumption. Our results suggest that efforts to reduce fuel consumption, costs, and emissions in fisheries need to be tailored to the nature of individual fisheries, as the relative roles of technology, behaviour, and management vary.

6. **Improving Understanding of Fisheries Functional Diversity by Exploring the Influence of Global Catch Reconstruction**

K. L. Nash, R. A. Watson, B. S. Halpern, E. A. Fulton, J. L. Blanchard, (2017). *Nature Scientific Reports* 7,

Global Fisheries; sustainability; planetary boundaries; marine ecology; policy

10.1038/s41598-017-10723-1, http://www.ecomarres.com/downloads/Functional.pdf

Functional diversity is thought to enhance ecosystem resilience, driving research focused on trends in the functional composition of fisheries, most recently with new reconstructions of global catch data. However, there is currently little understanding of how accounting for unreported catches (e.g. small-scale and illegal fisheries, bycatch and discards) influences functional diversity trends in global fisheries. We explored how diversity estimates varied among reported and unreported components of catch in 2010, and found these components had distinct functional fingerprints.

Incorporating unreported catches had little impact on global-scale functional diversity patterns. However, at smaller, management-relevant scales, the effects of incorporating unreported catches were large (changes in functional diversity of up to 46%). Our results suggest there is greater uncertainty about the risks to ecosystem integrity and resilience from current fishing patterns than previously recognized. We provide recommendations and suggest a research agenda to improve future assessments of functional diversity of global fisheries.

7. **Planetary Boundaries for a Blue Planet**

K. L. Nash, C. Cvitanovic, E. A. Fulton, B. S. Halpern, E. J. Milner-Gulland, R. A. Watson, J. L. Blanchard, (2017). *Nature Ecology and Evolution* 1,

Global Fisheries; marine ecology; functional traits; ecosystems; resilience; database

10.1038/s41559-017-0319-z,

Concepts underpinning the planetary boundaries framework are being incorporated into multilateral discussions on sustainability, influencing international environmental policy development. Research underlying the boundaries has primarily focused on terrestrial systems, despite the fundamental role of marine biomes for Earth system function and societal wellbeing, seriously hindering the efficacy of the boundary approach. We explore boundaries from a marine perspective. For each boundary, we show how improved integration of marine systems influences our understanding of the risk of crossing these limits. Better integration of marine systems is essential if planetary boundaries are to inform Earth system governance.

8. **Widely Used Marine Seismic Survey Air Gun Operations Negatively Impact Zooplankton**

R. D. McCauley, R. D. Day, K. M. Swadling, Q. P. Fitzgibbon, R. A. Watson, J. M. Semmens, (2017). *Nature Ecology and Evolution* 1,

seismic; zooplankton; marine; ecosystems; impacts

10.1038/s41559-017-0195, http://www.ecomarres.com/downloads/seismic.pdf

Zooplankton underpin the health and productivity of global marine ecosystems. Here we present evidence that suggests seismic surveys cause significant mortality to zooplankton populations. Seismic surveys are used extensively to explore for petroleum resources using intense, low-frequency, acoustic impulse signals. Experimental air gun signal exposure decreased zooplankton abundance when compared with controls, as measured by sonar (~3–4 dB drop within 15–30 min) and net tows (median 64% decrease within 1 h), and caused a two- to threefold increase in dead adult and larval zooplankton. Impacts were observed out to the maximum 1.2 km range sampled, which was more than two orders of magnitude greater than the previously assumed impact range of 10 m. Although no adult krill were present, all larval krill were killed after air gun passage. There is a significant and unacknowledged potential for ocean ecosystem function and productivity to be negatively impacted by present seismic technology.

9. **Farming and the Geography of Nutrient Production for Human Use**

M. Herrero, P. K. Thornton, B. Power, J. Bogard, R. Remans, S. Fritz, J. Gerber, G. C. Nelson, L. See, K. Waha, R. A. Watson, P. West, L. Samberg, J. van de Steeg, E. Stephenson, M. van Wijk, P. Havlik, (2017). *Lancet Planetary Health* 1, e33–42.

Global Fisheries; nutrition; biodiversity

, http://www.ecomarres.com/downloads/Nutrition.pdf

Globally, small and medium farms (≤ 50 ha) produce 51–77% of nearly all commodities and nutrients examined here. However, important regional differences exist. Large farms (>50 ha) dominate production in North America, South America, and Australia and New Zealand. In these regions, large farms contribute between 75% and 100% of all cereal, livestock, and fruit production, and the pattern is similar for other commodity groups. By contrast, small farms (≤ 20 ha) produce more than 75% of most food commodities in Sub-Saharan Africa, Southeast Asia, South Asia, and China. In Europe, West Asia and North Africa, and Central America, medium-size farms (20–50 ha) also contribute substantially to the production of most food commodities. Very small farms (≤ 2 ha) are important and have local significance in Sub-Saharan Africa, Southeast Asia, and South Asia, where they contribute to about 30% of most food commodities. The majority of vegetables (81%), roots and tubers (72%), pulses (67%), fruits (66%), fish and livestock products (60%), and cereals (56%) are produced in diverse landscapes (H>1·5). Similarly, the majority of global micronutrients (53–81%) and protein (57%) are also produced in more diverse agricultural landscapes (H>1·5). By contrast, the majority of sugar (73%) and oil crops (57%) are produced in less diverse ones (H≤ 1·5), which also account for the majority of global calorie production (56%). The diversity of agricultural and nutrient production diminishes as farm size increases. However, areas of the world with higher agricultural diversity produce more nutrients, irrespective of farm size.

10. **Assessing the Environmental Impacts of Seafood as Part of a Sustainable Diet**

A. Farmery, S. Jennings, C. Gardner, R. A. Watson, B. Green, (2017). *Fish and Fisheries* 18, 607–618.

aquaculture, food, greenhouse gas emissions, life cycle assessment, nutrition, wild-capture

10.1111/faf.12205, http://www.ecomarres.com/downloads/seafooddiet.pdf

The literature on sustainable diets is broad in its scope, and application yet is consist-ently supportive of a move away from animal- based diets towards more plant- based diets. The positioning of seafood within the sustainable diet literature is less clear. A literature review was conducted to examine how the environmental impacts of seafood consumption are assessed and what conclusions are being drawn about the inclusion of seafood in a sustainable diet. Seafood is an essential part of the global food system but is not adequately addressed in most of the sustainable diet literature. Aquaculture, the world's fastest growing food sector, was considered by very few papers. Seafood con-sumption was commonly presented as a dilemma due to the perceived trade- offs be-tween positive health outcomes from eating seafood and concerns of overfishing. A number of studies included seafood as part of their sustainable diet scenario, or as part of a diet that had lower impacts than current consumption. Most of the indicators used were biophysical, with a strong focus on greenhouse gas emissions, and very few stud-ies addressed biological or ecological impacts. The assessment of seafood was limited in many studies due to relevant data sets not being incorporated into the models used. Where they were used, data sources and methodological choices were often not stated thereby limiting the transparency of many studies. Both farmed and wild- capture pro-duction methods need to be integrated into research on the impacts of diets and future food scenarios to better understand and promote the benefits of sustainable diets.

11. **Naturalness as a Basis for Incorporating Marine Biodiversity into Life Cycle Assessment of Seafood.**

A. K. Farmery, S. Jennings, C. Gardner, R. A. Watson, B. Green, (2017). *The International Journal of Life Cycle Assessment*,

Life cycle assessment, biodiversity, land use, sea floor, seawater column, seafood, hemeroby, naturalness

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Methods to quantify biodiversity impacts through LCA are evolving for both land- and marine-based production systems, although typically independently from each other. An indicator for terrestrial food production systems that may be suitable to assess marine biodiversity, and is applicable across all food production systems, is a measure of hemeroby, or distance from the natural state. We explore the possibility of adapting this approach to marine systems to assess the impact of fishing on seawater column and seafloor systems.

The terrestrial hemeroby concept is adapted here for marine ecosystems. Two commercial fishery case studies are used to test the effectiveness of hemeroby in measuring the influence exerted by fishing practices on marine biodiversity. Available inventory data are used to score areas to a hemeroby class, following a semi-quantitative scoring matrix and seven-point scale, to determine how far the seafloor and seawater column are from their natural state. This assessment process may progress to the impact assessment stage involving characterisation of the hemeroby score, to determine the

Naturalness Degradation Potential (NDP) for use in calculating the Naturalness Degradation Indicator (NDI). The method builds on well-established processes for assessing fisheries within the Ecosystem-Based Fisheries Management framework, and is designed to enhance assessment of fishing impacts within LCA.

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12. **Considering Land-Sea Interactions and Trade-Offs for Food and Biodiversity**

R. S. Cottrell, A. Fleming, E. A. Fulton, K. L. Nash, R. A. Watson, J. L. Blanchard, (2017). *Global Change Biology*,

Land-sea, interactions, trade-offs, food production, food security, biodiversity, sustainable development

10.1111/gcb.13873, http://www.ecomarres.com/downloads/Interface.pdf

With the human population expected to near 10 billion by 2050, and diets shifting towards greater per-capita consumption of animal protein, meeting future food demands will place ever-growing burdens on natural resources and those dependent on them. Solutions proposed to increase the sustainability of agriculture, aquaculture, and capture fisheries have typically approached development from single sector perspectives. Recent work highlights the importance of recognising links among food sectors, and the challenge cross-sector dependencies create for sustainable food production. Yet without understanding the full suite of interactions between food systems on land and sea, development in one sector may result in unanticipated trade-offs in another. We review the interactions between terrestrial and aquatic food systems. We show that most of the studied land-sea interactions fall into at least one of four categories: ecosystem connectivity, feed interdependencies, livelihood interactions, and climate feedback. Critically, these interactions modify nutrient flows, and the partitioning of natural resource use between land and sea, amid a backdrop of climate variability and change that reaches across all sectors. Addressing counter-productive trade-offs resulting from land-sea links will require simultaneous improvements in food production and consumption efficiency, while creating more sustainable feed products for fish and livestock. Food security research and policy also needs to better integrate aquatic and terrestrial production to anticipate how cross-sector interactions could transmit change across ecosystem and governance boundaries into the future.

13. **Continental-Scale Hotspots of Pelagic Fish Abundance Inferred from Commercial Catch Records**

P. Bouchet, J. Meeuwig, Z. Huang, T. Letessier, S. Nichol, R. A. Watson, (2017). *Global Ecology and Biogeography*, 1-14.

submarine canyon, marine protected areas, pelagic fish, hotspot, topography, geomorphometrics, spatial modelling, random forest, catch standardisation

10.1111/geb.12619, http://www.ecomarres.com/downloads/Canyon.pdf

We compiled ten years of commercial fishing records from the Sea Around Us Project and derived relative abundance indices from standardised catch rates while accounting for confounding effects of effort, year, gear type and body mass. We used these indices to map pelagic “hotspots” over a 0.5°-resolution grid, and we built random forests to estimate the importance of 29 geophysical, oceanographic and anthropogenic predictors in explaining their locations. We additionally examined the spatial congruence between inferred hotspots and an extensive network of marine reserves, and determined whether patterns of co-occurrence deviated from random expectations using null model simulations. We identify three regional pelagic hotspots off the coast of Western Australia. (2) Geomorphometrics alone explained more than 50% of the variance in relative abundance of pelagic fish, and submarine canyon presence ranked as the most influential variable in the North bioregion. Seafloor rugosity and fractal dimension, salinity, ocean energy, current strength and human impacts were also identified as important predictors. (3) The spatial overlap between hotspots and marine reserves was limited, with most high-abundance areas primarily found in zones where anthropogenic activities are subject to few regulations. This study reveals that geomorphometrics are potentially valuable indicators of the distribution of mobile fish species and highlights the relevance of harnessing static topography as a blueprint for ocean zoning and spatial management.

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14. **Linked Sustainability Challenges and Trade-Offs among Fisheries, Aquaculture and Agriculture**

J. L. Blanchard, R. A. Watson, E. A. Fulton, R. S. Cottrell, K. L. Nash, A. Bryndum-Buchholz, M. Büchner, D. A. Carozza, W. Cheung, J. Elliott, L. N. K. Davidson, N. K. Dulvy, J. P. Dunne, T. D. Eddy, E. Galbraith, H. K. Lotze, O. Maury, C. Müller, D. P. Tittensor, S. Jennings, (2017). *Nature Ecology and Evolution* 1, 1240–1249.

fisheries;sustainability;Food security;global;agriculture

10.1038/s41559-017-0258-8, http://www.ecomarres.com/downloads/NEE2.pdf

Fisheries and aquaculture make a crucial contribution to global food security, nutrition and livelihoods. However, the UN Sustainable Development Goals separate marine and terrestrial food production sectors and ecosystems. To sustainably meet increasing global demands for fish, the interlinkages among goals within and across fisheries, aquaculture and agriculture sectors must be recognized and addressed along with their changing nature. Here, we assess and highlight development challenges for fisheries-dependent countries based on analyses of interactions and trade-offs between goals focusing on food, biodiversity and climate change. We demonstrate that some countries are likely to face double jeopardies in both fisheries and agriculture sectors under climate change. The strategies to mitigate these risks will be context-dependent, and will need to directly address the trade-offs among Sustainable Development Goals, such as halting biodiversity loss and reducing poverty. Countries with low adaptive capacity but increasing demand for food require greater support and capacity building to transition towards reconciling trade-offs. Necessary actions are context-dependent and include effective governance, improved management and conservation, maximizing societal and environmental benefits from trade, increased equitability of distribution and innovation in food production, including continued development of low input and low impact aquaculture.

15. **Global Fishing Capacity and Fishing Effort from 1950–2012**

J. D. Bell, R. A. Watson, Y. Ye, (2017). *Fish and Fisheries* 18, 489–505.

Fisheries management; fishing power; fishing energy use; fishing efficiency; global

10.1111/faf.12187, http://www.ecomarres.com/downloads/Effort3.pdf

Global marine wild capture landings have remained relatively stable for >20 years, however there is a lack of credible fishing capacity and effort information required to assess the likely sustainability and efficiency of the global fleet. As such, we estimated global fishing capacity and effort from 1950-2012 using a relatively comprehensive database developed by the FAO, supplemented by other data sources. Using random sampling techniques, we estimated the uncertainty surrounding many of our estimates enabling the identification of deficiencies and limitations. Global fishing capacity and effort increased rapidly from the late 1970's through to around 2010 before stabilising. The Asian fleet is more than an order of magnitude larger than any other region in both capacity and effort and continues to increase. Most other regions have stabilised and there have been considerable declines in Europe and to a lesser extent North America. Developed nations, as a whole, have decreased in both measures in recent years and are responsible for the stabilisation of the global trend. Developing and undeveloped countries are still increasing with the former having the largest fleet and showing the greatest relative increase and the socio-economic impacts of reversing these trends are likely to be high. The efficiency of the global fleet, in terms of watt days of fishing effort per tonnage of wild marine catch, is now less than in 1950 despite the considerable technological advances, and expansion throughout the world's oceans, that has occurred during this period of time.

16. **Global Fishing Capacity and Fishing Effort from 1950–2012 Corrigendum**

J. D. Bell, R. A. Watson, Y. Ye, (2017). *Fish and Fisheries* 18, 792-793.

Fisheries management; fishing power; fishing energy use; fishing efficiency; global

10.1111/faf.12234, http://www.ecomarres.com/downloads/Effort3_correction.pdf

Global marine wild capture landings have remained relatively stable for >20 years, however there is a lack of credible fishing capacity and effort information required to assess the likely sustainability and efficiency of the global fleet. As such, we estimated global fishing capacity and effort from 1950-2012 using a relatively comprehensive database developed by the FAO, supplemented by other data sources. Using random sampling techniques, we estimated the uncertainty surrounding many of our estimates enabling the identification of deficiencies and limitations. Global fishing capacity and effort increased rapidly from the late 1970's through to around 2010 before stabilising. The Asian fleet is more than an order of magnitude larger than any other region in both capacity and effort and continues to increase. Most other regions have stabilised and there have been considerable declines in Europe and to a lesser extent North America. Developed nations, as a whole, have decreased in both measures in recent years and are responsible for the stabilisation of the global trend. Developing and undeveloped countries are still increasing with the former having the largest fleet and showing the greatest relative increase and the socio-economic impacts of reversing these trends are likely to be high. The efficiency of the global fleet, in terms of watt days of fishing effort per tonnage of wild marine catch, is now less than in 1950 despite the considerable technological advances, and expansion throughout the world's oceans, that has occurred during this period of time.

17. **Provenance of Global Seafood**

R. A. Watson, B. S. Green, S. Tracey, A. Farmery, T. J. Pitcher, (2016). *Fish and Fisheries* 17, 585-595.

Export, import, mapping, Seafood consumption, provenance, seafood

10.1111/faf.12129, http://www.ecomarres.com/downloads/Provenance.pdf

Knowing where and how seafood is caught or farmed is central to empowering consumers, and the importers that supply them, with informed choices. Given the wide-ranging, complex and at times commercially sensitive nature of global seafood trade, it can prove very challenging to link imported seafood with information about its provenance. The databases involved are incomplete, at times vague and not harmonized. Here, we present a first attempt to link all global seafood imports through a virtual marketplace to exports and map their origins. Considerable work remains to ground-truth the specific origins of all seafood commodities. We illustrate the flow of seafood and its evolution since the 1970s when supporting records began. This work allows the impact of fishing or marine farming to be associated with seafood imports.

18. **Marine Foods Sourced from Farther as Their Use of Global Ocean Primary Production Increases.**

R. A. Watson, G. Nowara, K. Hartmann, B. S. Green, S. Tracey, C. G. Carter, (2015). *Nature communications* 6,

Seafood consumption; seafood production; Food security; Global Fisheries; Aquaculture

10.1038/ncomms8365, http://www.ecomarres.com/downloads/Farther.pdf

The growing human population must be fed, but historic land-based systems struggle to meet expanding demand. Marine production supports some of the world's poorest people but increasingly provides for the needs of the affluent, either directly by fishing or via fodderbased feeds for marine and terrestrial farming. Here we show the expanding footprint of humans to utilize global ocean productivity to feed themselves. Our results illustrate how incrementally each year, marine foods are sourced farther from where they are consumed and moreover, requires an increasing proportion of the ocean's primary productivity that underpins all marine life. Though mariculture supports increased consumption of seafood, it continues to require feeds based on fully exploited wild stocks. Here we examine the ocean's ability to meet our future demands to 2100 and find that even with mariculture supplementing near-static wild catches our growing needs are unlikely to be met without significant changes.

19. **Species Traits and Climate Velocity Explain Geographic Range Shifts in an Ocean Warming Hotspot**

J. M. Sunday, G. T. Pecl, S. Frusher, A. J. Hobday, N. Hill, N. J. Holbrook, G. J. Edgar, R. Stuart-Smith, N. Barrett, T.

Wernberg, R. A. Watson, D. A. Smale, E. A. Fulton, D. Slawinski, M. Feng, B. T. Radford, P. A. Thompson, A. E. Bates, (2015). *Ecology Letters*,

range shifts, climate change, species traits, range extension, climate velocity, functional traits, climate response

10.1111/ele.12474, http://www.ecomarres.com/downloads/Range.pdf

Species' ranges are shifting globally in response to climate warming, with substantial variability among taxa, even within regions. Relationships between range dynamics and intrinsic species traits may be particularly tractable in the ocean, where temperature more directly shapes species distributions. Here we test the possible role of species traits and climate velocity in driving the rate of range extensions in a region of rapid ocean warming. Climate expectation explained some variation in range shifts. However, including species traits more than doubled the variation explained. Swimming ability, omnivory, and latitudinal range size all have positive relationships with range extension rates, supporting hypotheses that increased dispersal capacity and ecological generalism promote range extensions. We find independent support for the hypothesis that species with narrow marine latitudinal ranges are out of equilibrium with climate. These findings suggest that small-ranging species are in double jeopardy, with a limited ability to escape warming and greater intrinsic vulnerability to stochastic threats.

20. **Winners and Losers in a World Where the High Seas Is Closed to Fishing.**

U. R. Sumaila, W. Y. Lam, D. D. Miller, L. Teh, R. A. Watson, D. Pauly, D. Zeller, W. W. L. Cheung , I. M. Côté, A. D. Rogers, C. M. Roberts, E. Sala, (2015). *Nature Scientific Reports* 5,

Global Fisheries, high seas, Exclusive Economic Zones, tuna

10.1038/srep08481, http://www.ecomarres.com/downloads/openocean.pdf

Fishing takes place in the high seas and Exclusive Economic Zones (EEZs) of maritime countries. Closing the former to fishing has recently been proposed in the literature and is currently an issue of debate in various international fora. We determine the degree of overlap between fish caught in these two areas of the ocean, examine how global catch might change if catches of straddling species or taxon groups increase within EEZs as a result of protection of adjacent high seas; and identify countries that are likely to gain or lose in total catch quantity and value following high-seas closure. We find that ,0.01% of commercial fish taxa are caught exclusively in the high seas, and if the catch of straddling taxa increases by 18% on average following closure because of spillover, there would be no loss in global catch. The Gini coefficient, which measures income inequality, would decrease from 0.66 to 0.33. Thus, closing the high seas could be catch-neutral while inequality in the distribution of fisheries benefits among the world's maritime countries could be reduced by 50%.

21. **Environmental and Economic Dimensions of Fuel Use in Australian Fisheries**

R. W. R. Parker, K. Hartmann, B. S. Green, C. Gardner, R. A. Watson, (2015). *Journal of Cleaner Production* 87, 78-86.

Fuel, australia, Fisheries, Fisheries, Fuel, Fuel consumption, Carbon footprint, Life cycle assessment, Oil prices

10.1016/j.jclepro.2014.09.081, http://www.ecomarres.com/downloads/Fuel_Parker.pdf

Fisheries globally are facing multiple sustainability challenges, including low fish stocks, overcapacity, unintended bycatch and habitat alteration. Recently, fuel consumption has joined this list of challenges, with increasing consumer demand for low-carbon food production and the implementation of carbon pricing mechanisms. The environmental impetus for improving fishery fuel performance is coupled with economic benefits of decreasing fuel expenditures as oil prices rise. Management options to improve the fuel performance of fisheries could satisfy multiple objectives by providing low-carbon fish products, improving economic viability of the industry, and alleviating pressure on overfished stocks. We explored the association of fuel consumption and fuel costs in a wide range of Australian fisheries, tracking trends in consumption and expenditure over two decades, to determine if there is an economic impetus for improving the fuel efficiency e and therefore carbon footprint e of the industry. In the years studied, Australian fisheries, particularly energy-intensive crustacean fisheries, consumed large quantities of fuel per kilogram of seafood product relative to global fisheries. Many fisheries improved their fuel consumption, particularly in response to increases in biomass and decreases in overcapacity. Those fisheries that improved their fuel consumption also saw a decrease in their relative fuel expenditure, partially counteracted by rising oil prices. Reduction in fuel use in some Australian fisheries has been substantial and this has resulted not from technological or operational changes but indirectly through fisheries management. These changes have mainly resulted from management decisions targeting ecological and economic objectives, so more explicit consideration of fuel use may help in extending these improvements.

22. **Fishing Access Agreements and Harvesting Decisions of Host and Distant Water Fishing Nations**

R. Nichols, S. Yamazaki, S. Jennings, R. A. Watson, (2015). *Marine Policy* 54, 77–85.

Fisheries, Access agreements, Tuna, Pacific island nations, Distant water fishing nations

10.1016/j.marpol.2014.12.019, http://www.ecomarres.com/downloads/access.pdf

The declaration of exclusive economic zones (EEZs) granted coastal states sovereign rights over the marine resources in their EEZs and enabled developing coastal states to legally charge access fees to distant water fishing (DWF) nations for access to the resources in these waters. Despite the potential for economic gains, however, the ability of coastal states to benefit from the granting of sovereign rights and to ensure the sustainable use of their fisheries resources depends on how domestic fishing effort responds to the harvesting decisions of the DWF nations. We develop a stylized bioeconomic model to explore the change in fishing behavior of host and DWF nations when the two nations enter into an access agreement with varying levels of access fee. We further conduct an econometric analysis of changes in Pacific island nations' harvesting behavior in response to the harvest decisions of DWF nations using data from the Western and Central Pacific tuna fishery. Our model results show that there is a range of variable access payment levels over which the host nation substitutes benefits from its domestic fishing activity with access payments from the DWF nation and that setting fees in this range can create a trap whereby host nations are forced to trade-off receiving a fair return to their fishery resources through access fees and retaining their own active fleet capacity. Our empirical analysis further shows a gradual shift in the way in which Pacific island host nations responded to the harvest decision of DWF nations as a result of the creation of the 200-nautical-mile EEZ.

23. **Is Fisheries Production within Large Marine Ecosystems Determined by Bottom-up or Top-Down Forcing?**

C. J. McOwen, W. W. L. Cheung, R. R. Rykaczewski, R. A. Watson, L. J. Wood, (2015). *Fish and Fisheries* 16, 623-632.

bottom-up; climate forcing; fishing effort; Large Marine Ecosystem; LME; top-down; fisheries production; primary production

10.1111/faf.12082, http://www.ecomarres.com/downloads/Production.pdf

Understanding the mechanisms driving fisheries production is essential if we are to accurately predict changes under climate change and exploit fish stocks in a sustainable manner. Traditionally studies have sought to distinguish between the two most prominent drivers, 'bottom-up' (resource driven) and 'top-down' (consumer driven), however, this dichotomy is increasingly proving to be artificial; as the relative importance of each mechanism has been shown to vary through space and time. Nevertheless, the reason why one predominates over another within a region remains largely unknown. To address this gap in understanding we identified the dominant driver of commercial landings within 47 ecosystems, encompassing a wide range of biogeochemical conditions and fishing practices in order to elucidate general patterns. We show that bottom-up and top-down effects vary consistently with past fishing pressure and oceanographic conditions; bottom-up control predominates within productive, overfished regions and top-down in relatively unproductive and under-exploited areas. We attribute these findings to differences in the species composition and oceanographic properties of regions, together with variation in fishing practices and (indicative) management effectiveness. Collectively, our analyses suggest that despite the complexity of ecological systems it is possible to elucidate a number of generalities. Such knowledge could be used to increase the parsimony of ecosystem models and to move a step forward in predicting how the global ocean, particularly fisheries productivity, will respond to climate change.

24. **When Is a Fishery Sustainable?**

R. Hilborn, E. A. Fulton, B. S. Green, K. Hartmann, S. R. Tracey, R. A. Watson, (2015). *Canadian Journal Fisheries and Aquatic Sciences* 72, 1433-1441.

sustainability; Global Fisheries; Fisheries management; stock assessment

10.1139/cjfas-2015-0062, http://www.ecomarres.com/downloads/Sustainable.pdf

Despite the many scientific and public discussions on the sustainability of fisheries, there are still great differences in both perception and definition of the concept. Most authors now suggest that sustainability is best defined as the ability to sustain goods and services to human society, with social and economic factors to be considered along with environmental impacts. The result has been that each group (scientists, economists, NGOs etc.) defines "sustainable seafood" using whatever criteria it considers most important, and the same fish product may be deemed sustainable by one group and totally unsustainable by another one. We contend, however, that there is now extensive evidence that an ecological focus alone does not guarantee long-term sustainability of any form and that seafood sustainability must consistently take on a socio-ecological perspective if it is to be effective across cultures and in the future. The sustainability of seafood production depends not on the abundance of a fish stock, but on the ability of the fishery management system to adjust fishing pressure to appropriate levels. While there are scientific standards to judge the sustainability of food production, once we examine ecological, social and economic aspects of sustainability there is no unique scientific standard.

25. **Life Cycle Assessment of Wild Capture Prawns: Expanding Sustainability Considerations in the Australian Northern Prawn Fishery.**

A. Farmery, C. Gardner, B. Green, S. Jennings, R. Watson, (2015). *Journal of Cleaner Production* 87, 96-104.

Northern prawn fishery, Banana and tiger prawn, Shrimp trawling, Greenhouse gas emissions, Sustainable seafood, LCA, prawn, shrimp, trawling

10.1016/j.jclepro.2014.10.063, http://www.ecomarres.com/downloads/NPF_LCA.pdf

Prawns and shrimp are among the most popular seafood consumed globally and their production is responsible for a range of environmental impacts in wild capture fisheries and associated supply chains. Management of the Australian Northern Prawn Fishery has been promoted as a sustainable model for other countries to emulate, although broader environmental impacts, such as those relating to energy and water use or greenhouse gas emissions are not currently monitored under sustainability assessments. We use life cycle assessment (LCA) to assess the environmental impacts of the white banana prawn (Fenneropenaeus merguiensis). Fishing operations were the main source of impacts for the supply chain examined, contributing 4.3 kg CO_2e kg^{-1} prawn or 63% of the overall global warming potential. This result was lower than emissions reported for other prawn species, including tiger prawns from the same fishery. Processing and storage were key contributors to ecotoxicity while transport made a negligible contribution to any impact category. We discuss how LCA can complement existing fisheries management, and broaden current seafood sustainability assessments including the potential for emerging fishery-specific indicators to improve the efficacy of seafood LCAs.

26. **Domestic or Imported? An Assessment of Carbon Footprints and Sustainability of Seafood Consumed in Australia**

A. K. Farmery, B. G. Green, S. Jennings, R. A. Watson, C. Gardner, (2015). *Environmental Science & Policy* 54, 35-43.

imports, seafood trade, supply chain, life cycle assessment, food miles, sustainable seafood, Australia

, http://www.ecomarres.com/downloads/Anna_Seafood.pdf

The distance between where food is produced and consumed is increasing, and is often taken as evidence of an unsustainable global food system. Seafood is a highly traded commodity yet seafood sustainability assessments do not typically consider the impacts of the movement of products beyond the fishery or farm. Here we use life cycle assessment to examine the carbon footprint of the production and distribution of select seafood products that are consumed in Australia and determine differences in the sustainability of imports and their domestically produced counterparts. We found that the distance food is transported is not the main determinant of food sustainability. Despite the increased distance between production and consumption, carbon footprints of meals from imported seafood are similar to meals consisting of domestically produced seafood, and sometimes lower, depending on the seafood consumed. In combining LCA with existing seafood sustainability criteria the trade-offs between sustainability targets become more apparent. Carbon 'footprinting' is one metric that can be incorporated into in assessments of sustainability, thereby demonstrating a broader perspective of the environmental cost of food production and consumption.

27. **Reinventing Residual Reserves in the Sea: Are We Favouring Ease of Establishment over Need for Protection?**

R. Devillers, R. L. Pressey, A. Grech, J. N. Kittinger, G. J. Edgar, T. Ward, R. Watson, (2015). *Aquatic Conservation* 25, 480-504.

marine protected areas; mpa; residual reserves; global

10.1002/aqc.2445, http://www.ecomarres.com/downloads/aqc1.pdf

1. As systems of marine protected areas (MPAs) expand globally, there is a risk that new MPAs will be biased toward places that are remote or unpromising for extractive activities, and hence follow the trend of terrestrial protected areas in being 'residual' to commercial uses. Such locations typically provide little protection to the species and ecosystems that are most exposed to threatening processes. 2. There are strong political motivations to establish residual reserves that minimize costs and conflicts with users of natural resources. These motivations will likely remain in place as long as success continues to be measured in terms of area (km2) protected. 3. The global pattern of MPAs was reviewed and appears to be residual, supported by a rapid growth of large, remote MPAs. The extent to which MPAs in Australia are residual nationally and also regionally within the Great Barrier Reef (GBR) Marine Park was also examined. 4. Nationally, the recently announced Australian Commonwealth marine reserves were found to be strongly residual, making almost no difference to 'business as usual' for most ocean uses. Underlying this result was the imperative to minimize costs, but without the spatial constraints of explicit quantitative objectives for representing bioregions or the range of ecological features in highly protected zones. 5. In contrast, the 2004 rezoning of the GBR was exemplary, and the potential for residual protection was limited by applying a systematic set of planning principles, such as representing a minimum percentage of finely subdivided bioregions. Nonetheless, even at this scale, protection was uneven between bioregions. Within bioregion heterogeneity might have led to no-take zones being established in areas unsuitable for trawling with a risk that species assemblages differ between areas protected and areas left available for trawling. 6. A simple four-step framework of questions for planners and policy makers is proposed to help reverse the emerging residual tendency of MPAs and maximize their effectiveness for conservation. This involves checks on the least-cost approach to establishing MPAs in order to avoid perverse outcomes.

28. **The Global Ocean Is an Ecosystem: Simulating Marine Life and Fisheries**

V. Christensen, M. Coll, J. Buszowski, W. W. L. Cheung , T. L. Frölicher, J. Steenbeek, C. A. Stock, R. A. Watson, C. J. Walters, (2015). *Global Ecology and Biogeography* 24, 507–517.

Ecosystem model; end-to-end model; fish biomass trends; fish catches; food security; model tuning; seafood production; world ocean

10.1111/geb.12281, http://www.ecomarres.com/downloads/globalocean.pdf

There has been considerable effort allocated to understanding the impact of climate change on our physical environment, but comparatively little to how life on

Earth and ecosystem services will be affected. Therefore, we have developed a spatial–temporal food web model of the global ocean, spanning from primary producers through to top predators and fisheries. Through this, we aim to evaluate how alternative management actions may impact the supply of seafood for future generations.

29. **Primary Productivity Demands of Global Fishing Fleets**

R. Watson, D. Zeller, D. Pauly, (2014). *Fish and Fisheries* 15, 231-241.

primary production;Large Marine Ecosystem; LME; global fishing fleets; marine fishing

10.1111/faf.1201, http://www.ecomarres.com/downloads/ppr.pdf

To be sustainable the extractive process of fishing requires biomass renewal via primary production driven by solar energy. Primary production required (PPR) estimates how much primary production is needed to replace the biomass of fisheries landings removed from marine ecosystems. Here we examine the historical fishing behavior of global fishing fleets, which parts of the food web they rely on, which ecosystems they fish and how intensively. Highly mobile European and Asian fleets have moved to ever more distant productive waters since the 1970s, especially once they are faced with the costs of access agreements for Exclusive Economic Zones (EEZs) declared by host countries. We examine fleet PPR demands in the context of Large Marine Ecosystems (LME) which are frequently fished with PPR demands well above their average primary productivity (PP). In some cases this was mitigated by subsequent emigration of fleets or by management intervention. Fleet movements, however, have stressed additional marine areas, including the EEZs of developing countries. This suggests the potential for spatial serial depletion, if fishing capacity is not reduced to more sustainable PP removal levels. Fundamentally, fishing is limited by solar-powered PP limits. Fishing beyond solar production has occurred but in the future, marine systems may not be as forgiving, especially if overfishing and climate change compromise their resilience.

30. **The Global Contribution of Forage Fish to Marine Fisheries and Ecosystems**

E. K. Pikitch, J. R. Konstantine, T. E. Essington, C. Santora, D. Pauly, R. Watson, U. R. Sumaila, P. D. Boersma, I. L. Boyd, D. O. Conover, P. Cury, S. S. Heppell, E. D. Houde, M. Mangel, E. Plaganyi-Lloyd, K. Sainsbury, R. S. Steneck, T. M. Geers, N. Gownaris, S. P. Munch, (2014). *Fish and Fisheries* 15, 43-64.

ecosystem-based management; ecosystem service; fisheries value; forage fish; supportive values; trade-offs

10.1111/f, http://www.ecomarres.com/downloads/ForageFish.pdf

Forage fish play a pivotal role in marine ecosystems and economies worldwide by sustaining many predators and fisheries directly and indirectly. We estimate global forage fish contributions to marine ecosystems through a synthesis of 72 published Ecopath models from around the world. Three distinct contributions of forage fish were examined: 1) the ecological support service of forage fish to predators in marine ecosystems, 2) the total catch and value of forage fisheries, and 3) the support service of forage fish to the catch and value of other commercially targeted predators. Forage fish use and value varied by latitude and ecosystem type, and exhibited patterns across these groups. Forage fish supported many kinds of predators, including fish, seabirds, marine mammals and squid. Overall, forage fish contribute a total of about $16.9 billion USD to global fisheries values annually, i.e. 20% of the global ex-vessel catch values of all marine fisheries combined. While the global catch value of forage fisheries was $5.6 billion, fisheries supported by forage fish were more than twice as valuable ($11.3 billion). These estimates provide important information for evaluating the trade-offs of various uses of forage fish across ecosystem types, latitudes, and globally. We did not estimate a monetary value for supportive contributions of forage fish to recreational fisheries or to uses unrelated to fisheries, thus the estimates of economic value reported herein understate the global value of forage fishes.

31. **Energy Prices and (Sea)Food Security**

N. Pellitier, J. André, A. Charef, D. Damalas, B. Green, R. Parker, R. Sumaila, G. Thomas, R. Tobin, R. Watson, (2014). *Global Environmental Change* 24, 30-41.

food security; energy price; fuel; fisheries; aquaculture; adaptive capacity; vulnerability

101016/jgloenvcha201311014, http://www.ecomarres.com/downloads/Fuel2.pdfFuel

Fish resources are critical to the food security of many nations. Similar to most contemporary food systems, much of fisheries and aquaculture resource supply chains are heavily dependent on fossil fuels. Energy price increases and volatility may hence undermine food security in some contexts. Here, we explore the relationships between energy price changes, fish resource supply chain viability, seafood availability and food security outcomes – both for producers and consumers of fish resources. We begin by characterizing the energy intensities of fish resource supply chains, which are shown to be highly variable. We subsequently assess the comparative magnitude and distribution of potential food security impacts of energy price increases for nation states by scoring and ranking countries against a set of vulnerability criteria including metrics of national exposure, sensitivity and adaptive capacity. Considerable variability in the vulnerability of populations and high levels of exposure for already food-insecure populations are apparent. Developed countries are likely to be most exposed to the effects of energy price increases due to their high rates of fleet motorization and preference for energy-intensive seafood products. However, heavy reliance on seafood as a source of food and income, as well as limited national adaptive capacity, translates into greater overall vulnerability in developing countries. At the level of individual producers, a variety of adaptation options are available that may serve to reduce vulnerability to energy price changes and hence contribute to increased food security for producers and consumers, but uptake capacity depends on numerous situational factors.

32. **Tropical Marginal Seas: Priority Regions for Managing Marine Biodiversity and Ecosystem Function**

A. D. McKinnon, A. Williams, J. Young, D. Ceccarelli, P. Dunstan, R. J. W. Brewin, R. Watson, R. Brinkman, M. Cappo, S. Duggan, R. Kelley, K. Ridgway, D. Lindsay, D. Gledhill, T. Hutton, A. Richardson, J., (2014). *Annual Review of Marine Science* 6, 1-23.

coral reef; fisheries; pelagic; deep sea; transboundary management

10.1146/annurev-marine-010213-135042, http://www.ecomarres.com/downloads/Marginal.pdf

Tropical marginal seas (TMSs) are natural subregions of tropical oceans containing biodiverse ecosystems with conspicuous, valued, and vulnerable biodiversity assets. They are focal points for global marine conservation because they occur in regions where human populations are rapidly expanding. Our review of 11 TMSs focuses on three key ecosystems—coral reefs and emergent atolls, deep benthic systems, and pelagic biomes—and synthesizes, illustrates, and contrasts knowledge of biodiversity, ecosystem function, interaction between adjacent habitats, and anthropogenic pressures. TMSs vary in the extent that they have been subject to human influence—from the nearly pristine Coral Sea to the heavily exploited South China and Caribbean Seas—but we predict that they will all be similarly complex to manage because most span multiple national jurisdictions.We conclude that developing a structured process to identify ecologically and biologically significant areas that uses a set of globally agreed criteria is a tractable first step toward effective multinational and transboundary ecosystem management of TMSs.

33. **Where the Waters Meet: Sharing Ideas and Experiences between Inland and Marine Realms to Promote Sustainable Fisheries Management.**

S. J. Cooke, R. Arlinghaus, D. M. Bartley, T. D. Beard, I. G. Cowx, T. E. Essington, O. P. Jensen, A. Lynch, W. W. Taylor, R. Watson, (2014). *Canadian Journal of Fisheries and Aquatic Sciences* 71, 1593-1601.

fisheries management,freshwater,inland fisheries,global fisheries,marine fisheries,sustainability

10.1139/cjfas-2014-0176, http://www.ecomarres.com/downloads/fresh1.pdf

Although inland and marine environments, their fisheries, fishery managers, and the realm-specific management approaches are often different, there are a surprising number of similarities that frequently go unrecognized. We contend that there is much to be gained by greater cross-fertilization and exchange of ideas and strategies between realms and the people who manage them. The purpose of this paper is to provide examples of the potential or demonstrated benefits of working across aquatic boundaries for enhanced sustainable management of the world's fisheries resources. Examples include the need to: (1) engage in habitat management and protection as the foundation for fisheries, (2) rethink institutional arrangements and management for open access fisheries systems, (3) establish 'reference points' and harvest control rules, (4) engage in integrated management approaches, (5) reap conservation benefits from the link to fish as food, and (6) reframe conservation and management of fish to better engage the public and industry. Cross-fertilization and knowledge transfer between realms could be realized using environment-independent curricula and symposia, joint scientific advisory councils for management, integrated development projects, and cross-realm policy dialogue. Given the interdependence of marine and inland fisheries, promoting discussion between the realms has the potential to promote meaningful advances in managing global fisheries. .

34. **Defining and Observing Stages of Climate-Mediated Range Shifts in Marine Systems.**

A. E. Bates, G. Pecl, S. Frusher, A. J. Hobday, T. Wernberg, D. A. Smale, J. M. Sunday, R. K. Colewell, N. Dulvy, G. J. Edgar, M. Feng, E. A. Fulton, N. Hill, N. Holbrook, B. T. Radford, D. Slawinski, P. A. Thompson, R. A. Watson, (2014). *Global Environmental Change* 26, 27-38.

species; redistribution; range; attribution; prediction; biogeography; warming; climate change; abundance–occupancy relationship

10.1016/j.gloenvcha.2014.03.009, http://www.ecomarres.com/downloads/Stages.pdf

Climate change is transforming the structure of biological communities through the geographic extension and contraction of species' ranges. Range edges are naturally dynamic, and shifts in the location of range edges occur at different rates and are driven by different mechanisms. This leads to challenges when seeking to generalize responses among taxa and across systems. We focus on warming-related range shifts in marine systems to describe extensions and contractions as stages. Range extensions occur as a sequence of (1) arrival, (2) population increase, and (3) persistence. By contrast, range contractions occur progressively as (1) performance decline, (2) population decrease and (3) local extinction. This stage-based framework can be broadly applied to geographic shifts in any species, life-history stage, or population subset. Ideally the probability of transitioning through progressive range shift stages could be estimated from empirical understanding of the various factors influencing range shift rates. Nevertheless, abundance and occupancy data at the spatial resolution required to quantify range shifts are often unavailable and we suggest the pragmatic solution of considering observations of range shifts within a confidence framework incorporating the type, amount and quality of data. We use case studies to illustrate how diverse evidence sources can be used to stage range extensions and contractions and assign confidence that an observed range shift stage has been reached. We then evaluate the utility of trait-based risk (invasion) and vulnerability (extinction) frameworks for application in a range shift context and find inadequacies, indicating an important area for development. We further consider factors that influence rates of extension and contraction of range edges in marine habitats. Finally, we suggest approaches required to increase our capacity to observe and predict geographic range shifts under climate change.

35. **Fishing Down the Deep: Accounting for within-Species Changes in Depth of Fishing.**

R. A. Watson, T. Morato, (2013). *Fisheries Research* 140, 63-65.

deep-sea; deep-water fisheries; depth of fishing; fishing deeper; global fisheries; coastal

10.1016/j.fishres.2012.12.004, http://www.ecomarres.com/downloads/deeper2.pdf

New estimates of the global mean depth of fishing, which consider both the between and within species changes over time, showed a stronger shift to deeper water than estimated previously based only on between-species changes. The new estimates show a linear increase in the mean depth of fishing of 62.5m decade-1, corresponding to an increase of about 350m for the period since 1950. These values are about 5 times higher than those obtained by using between-species change in catch composition over time, suggesting that deep water species and habitats are under a more serious threat from fishing than hitherto assumed.

36. **Coastal Catch Transects as a Tool for Studying Global Fisheries**

R. Watson, D. Pauly, (2013). *Fish and Fisheries* 15, 445-455.

cross-sectional; transects; global fisheries; coastal; Large Marine Ecosystems; LME; Exclusive Economic Zones: EEZ

10.1111/faf.1202, http://www.ecomarres.com/downloads/transect.pdf

We present a new, intuitive approach for the representation of fisheries catches within profiles perpendicular to coast of the Exclusive Economic Zones (EEZ) of countries, or of Large Marine Ecosystems (LME). These ‘catch transects’ show where catch is extracted in the water column and near the sea bottom on plots of log-bathymetry versus log-distance offshore, and thus allow for representation of the catch density of pelagic and benthic fisheries. Hence, they also allow direct visual comparison of the intensity of fishing through time and space. The California Current, North Sea and the South China Sea LMEs and the EEZs of Australia, Canada, Chile, China, India and Thailand are presented as examples, revealing the general intensification and extension of fishing offshore and into the depths over the decades from the 1950s. Catch transects reveal how these trends have accelerated in some areas, but surprisingly, have reversed themselves in some others. It is proposed that these catch transects will be particularly useful for communicating the results of large scale fisheries studies to a wide spectrum of groups ranging from the fishing industry to the general public.

37. **The Changing Face of Global Fisheries - the 1950s Vs. The 2000s**

R. Watson, D. Pauly, (2013). *Marine Policy* 42, 1-4.

global fisheries; marine; change; history

10.1016/j.marpol.2013.01.022, http://www.ecomarres.com/downloads/cartogram.pdf

Spatialized catch and effort data, representing the world’s marine fisheries in the 1950s and the 2000s are presented in form of cartograms, i.e., global maps in which the surface areas of continents are made proportional to the magnitude of the annual catches and fishing effort by their fleets. This is complemented by an analysis of the flows of seafood between the continents in whose waters the fish were captured, in the 1950s and 2000s, and the continents where fleets originated. Such broad-brush analyses of temporal changes and trade patterns are helpful to understand major trends of fisheries, which, we argue, are increasingly dominated by scarcity of fish, and competition, notably off the coast of West Africa, and in newly accessed polar waters.

38. **Global Marine Yield Halved as Fishing Intensity Redoubles**

R. A. Watson, W. W. L. Cheung, J. A. Anticamara, R. U. Sumaila, D. Zeller, D. Pauly, (2013). *Fish and Fisheries* 14, 493–503.

fishing effort; fishing intensity; spatial expansion; yield

10.1111/j.1467-2979.2012.00483.x, http://www.ecomarres.com/downloads/cpue.pdf

There is widespread concern and debate about the state of global marine resources and the ecosystems supporting them, notably global fisheries, as catches now generally stagnate or decline. Many fisheries are not assessed by standard stock assessment methods including many in the world’s most biodiverse areas. Though simpler methods using widely available catch data are available, these are often discounted largely because data on fishing effort that contributed to the changes in catches are mostly not considered. We analyse spatial and temporal patterns of global fishing effort and its relationship with catch to assess the status of the world’s fisheries. The study reveals that fleets now fish all of the world’s oceans and have increased in power by an average of 10-fold (25-fold for Asia) since the 1950s. Significantly, for the equivalent fishing power expended, landings from global fisheries are now half what they were a half-century ago, indicating profound changes to supporting marine environments. This study provides another dimension to understand the global status of fisheries.

39. **Ecosystem Model of Tasmanian Waters Explores Impacts of Climate-Change Induced Changes in Primary Productivity**

R. Watson, G. Nowara, S. Tracey, B. Fulton, C. Bulman, G. Edgar, N. Barrett, J. Lyle, S. Frusher, C. Buxton, (2013). *Ecological Modelling*,

climate-induced changes; climate change; marine; ecosystem model; primary productivity

10.1016/j.ecolmodel.2012.05.008, http://www.ecomarres.com/downloads/CERF.pdf

An Ecopath with Ecosim (EwE) model was developed that represents the marine shelf environment surrounding the island state of Tasmania (south of mainland Australia). Climate change scenarios representing a range of potential impacts (30% increase or decrease over a century) on marine primary productivity were investigated. Temperature changes and other impacts were not investigated. This analysis uncovered an asymmetric set of system responses. Modeled increases in primary productivity predict increases in the biomass of most groups, especially shallow filter-feeders (which includes oysters), fished macrozoobenthos which includes rock lobsters (Jasus edwardsii) and octopus. In contrast the group of unfished macrozoobenthos (sea stars, whelks) decreased their relative biomass as primary productivity increased. All modeled fisheries responded to varying primary production levels. The most responsive modeled fisheries were for flathead (Platycephalidae) and for those offshore. Of the groups of special conservation interest (marine mammals and seabirds) the most responsive was the dolphin group – though all responded.

40. **Response to Removing Biases in Forecasts of Fishery Status**

U. T. Srinivasan, W. W. L. Cheung, R. Watson, U. R. Sumaila, (2013). *Journal of Bioeconomics* 16, 221-222.

overfishing; fisheries management; depletion; sustainability

10.1007/s10818-013-9160-x, http://www.ecomarres.com/downloads/Bias2.pdf

Previously in this journal, we demonstrated an empirical relationship between maximum sustainable yield (MSY) and historical maximum catch (Cmax) for fishery stocks off the Northeast U.S.—a relationship we then applied to estimate the potential catch losses from unsustainable fishing worldwide (Srinivasan et al. 2010). Two studies have since found similar relationships between MSY and maximum catch using larger regional datasets (Froese et al. 2012; Halpern et al. 2012). In a third paper in this issue of the Journal of Bioeconomics, Costello et al. (in press) update the MSY- Cmax relationship in two ways. First, they correct for the “retransformation bias” (Duan 1983) omitted in our earlier analysis, and second, they reparametrize the model using data for 109 stocks from the RAM II global database of stock assessments (Ricard et al. 2011). Their updated model is arguably more representative of global fisheries than the one we used (Srinivasan et al. 2010), and when we apply it to re-estimate global catch losses to overfishing over 1950-2004, we find that our original conclusions are strengthened.

41. **China’s Distant Water Fisheries in the 21st Century.**

D. Pauly, D. Belhabib, R. Blomeyer, W. Cheung, A. Cisneros-Montemayor, D. Copeland, S. Harper, V. Lam, Y. Mai, F. Le Manach, H. Österblom, K. Mok, L. van der Meer, A. Sanz, S. Shon, U. Sumaila, W. Swartz, R. Watson, Y. Zhai, D. Zeller, (2013). *Fish and Fisheries* 15, 474-488.

China; distant water; fishing; history

10.1111/faf.12032, http://www.ecomarres.com/downloads/China2.pdf

We conservatively estimate the distant-water fleet catch of the People’s Republic of China for 2000–2011, using a newly assembled database of reported occurrence of Chinese fishing vessels in various parts of the world and information on the annual catch by vessel type. Given the unreliability of official statistics, uncertainty of results was estimated through a regionally stratified Monte Carlo approach, which documents the presence and number of Chinese vessels in Exclusive Economic Zones and then multiplies these by the expected annual catch per vessel. We find that China, which over-reports its domestic catch, substantially under-reports the catch of its distant-water fleets. This catch, estimated at 4.6 million t year-1 (95% central distribution, 3.4–6.1 million t year-1) from 2000 to 2011 (compared with an average of 368 000 t year-1 reported by China to FAO), corresponds to an exvessel landed value of 8.93 billion € year-1 (95% central distribution, 6.3–12.3 billion). Chinese distant-water fleets extract the largest catch in African waters (3.1 million t year-1, 95% central distribution, 2.0–4.4 million t), followed by Asia (1.0 million t year-1, 0.56–1.5 million t), Oceania (198 000 t year-1, 144 000–262 000 t), Central and South America (182 000 t year-1, 94 000–299 000 t) and Antarctica (48 000 t year-1, 8 000–129 000 t). The uncertainty of these estimates is relatively high, but several sources of inaccuracy could not be fully resolved given the constraints inherent in the underlying data and method, which also prevented us from distinguishing between legal and illegal catch.

42. **Exploring Patterns of Seafood Provision Revealed in the Global Ocean Health Index.**

K. M. Kleisner, C. Longo, M. Coll, B. S. Halpern, D. Hardy, S. K. Katona, F. Le Manach, D. Pauly, A. A. Rosenberg, S. F. Samhouri, C. Scarborough, U. R. Sumaila, R. Watson, D. Zeller, (2013). *AMBIO: a Journal of the Human Environment* 42, 910-992.

indicator; status; assessment; ocean health; global

10.1007/s13280-013-0447-x, http://www.ecomarres.com/downloads/SF_Ambio.pdf

Sustainable provision of seafood is a fundamental component of healthy marine ecosystems. As such, the Ocean Health Index includes a model for sustainable seafood provision. Here we critically review this model, and explore the implications of knowledge gaps, scale of analysis, choice of reference points, measures of sustainability, and quality of input data. Global patterns for fisheries are positively related to human development and latitude, whereas patterns for mariculture are most closely associated with economic importance of seafood. Sensitivity analyses show that scores are robust to several model assumptions, but highly sensitive to choice of reference points and, for fisheries, extent of time series available to estimate landings. We show how results for Food Provision may be interpreted and used, and we evaluate which modifications show the greatest potential for improvements.

43. **Global Reductions in Seafloor Biomass in Response to Climate Change**

D. O. B. Jones, A. Yool, C. Wei, S. A. Henson, H. A. Ruhl, R. A. Watson, M. Gehlen, (2013). *Global Change Biology* 20, 1861–1872.

benthic; climate change; seafloor

4101111/gcb12480, http://www.ecomarres.com/downloads/Benthic.pdf

Seafloor organisms are vital for healthy marine ecosystems, contributing to elemental cycling, benthic remineralization, and ultimately sequestration of carbon. Deep-sea life is primarily reliant on the export flux of particulate organic carbon from the surface ocean for food, but most ocean biogeochemistry models predict global decreases in export flux resulting from 21st century anthropogenically induced warming. Here we show that decadal-to-century scale changes in carbon export associated with climate change lead to an estimated 5.2% decrease in future (2091–2100) global open ocean benthic biomass under RCP8.5 (reduction of 5.2 Mt C) compared with contemporary conditions (2006–2015). Our projections use multi-model mean export flux estimates from eight fully coupled earth system models, which contributed to the Coupled Model Intercomparison Project Phase 5, that have been forced by high and low representative concentration pathways (RCP8.5 and 4.5, respectively). These export flux estimates are used in conjunction with published empirical relationships to predict changes in benthic biomass. The polar oceans and some upwelling areas may experience increases in benthic biomass, but most other regions show decreases, with up to 38% reductions in parts of the northeast Atlantic. Our analysis projects a future ocean with smaller sized infaunal benthos, potentially reducing energy transfer rates though benthic multicellular food webs. More than 80% of potential deep-water biodiversity hotspots known around the world, including canyons, seamounts, and cold-water coral reefs, are projected to experience negative changes in biomass. These major reductions in biomass may lead to widespread change in benthic ecosystems and the functions and services they provide.

44. **Signature of Ocean Warming in Global Fisheries Catch.**

W. W. L. Cheung , R. Watson, D. Pauly, (2013). *Nature* 497, 365-368.

climate change; ocean warming; global; fisheries

10.1038/nature12156, http://www.ecomarres.com/downloads/warm.pdf

Marine fishes and invertebrates respond to ocean warming through distribution shifts, generally to higher latitudes and deeper waters. Consequently, fisheries should be affected by ‘tropicalization’ of catch (increasing dominance of warm-water species). However, a signature of such climate-change effects on global fisheries catch has so far not been detected. Here we report such an index, the mean temperature of the catch (MTC), that is calculated from the average inferred temperature preference of exploited species weighted by their annual catch. Our results show that, after accounting for the effects of fishing and large-scale oceanographic variability, global MTC increased at a rate of 0.19 degrees Celsius per decade between 1970 and 2006, and non-tropical MTC increased at a rate of 0.23 degrees Celsius per decade. In tropical areas, MTC increased initially because of the reduction in the proportion of subtropical species catches, but subsequently stabilized as scope for further tropicalization of communities became limited. Changes in MTC in 52 large marine ecosystems, covering the majority of the world’s coastal and shelf areas, are significantly and positively related to regional changes in sea surface temperature. This study shows that ocean warming has already affected global fisheries in the past four decades, highlighting the immediate need to develop adaptation plans to minimize the effect of such warming on the economy and food security of coastal communities, particularly in tropical regions.

45. **Global Ex-Vessel Fish Price Database Revisited: A New Approach for Estimating ‘Missing’prices**

W. Swartz, R. Sumaila, R. Watson, (2012). *Environmental and Resource Economics*, 1-14.

price; value; global marine fisheries

10.1007/s10640-012-9611, http://www.ecomarres.com/downloads/fishprice.pdf

The Global Ex-vessel Fish Price Database (Ex-vessel DB) reported in Sumaila et al. (J Bioecon 9(1):39–51, 2007) was the first comprehensive database that presents average annual ex-vessel prices for all commercially exploited marine fish stocks by nationality of the fishing fleet. It contained over 30,000 reported price items, covering the period from 1950 to the present, and supplemented missing prices with estimates based on prices from a different year, species group or fleet nationality. This paper describes a revised missing price estimation approach, focused on the computation of annual average international prices for each species group, adjusted to domestic prices using the real exchange rate based on national purchasing power parity. Key advantages of the new approach are that it allows a larger number of reported prices to be used in the price estimation, and accounts for relative price level differences that exist between countries. Our new approach should improve the estimates in regions where reported prices are scarce or non-existent by linking domestic prices to the trends in international prices. Our analysis, based on the revised ex-vessel price estimates (in real 2005 USD), shows that the global marine fisheries landings have generated total value of USD 4.2 trillion since 1950, including USD 100 billion in 2005.

46. **Impact of the Deepwater Horizon Well Blowout on the Economics of U.S. Gulf Fisheries**

U. R. Sumaila, A. Cisneros-Montemayor, A. Dyck, L. Huang, W. Cheung, J. Jacquet, K. Kleisner, V. Lam, A. McCrea-Strub, W. Swartz, R. Watson, D. Zeller, D. Pauly, (2012). *Canadian Journal Fisheries and Aquatic Sciences* 69, 499-510.

oil spill; marine ecosystems; ecological impact; profit; wages

10.1139/F2011-171, http://www.ecomarres.com/downloads/GulfSpill2.pdf

Marine oil spills usually harm organisms at two interfaces, near the water surface and on shore. However, due to the depth of the April 2010 Deepwater Horizon well blowout, deeper parts of the Gulf of Mexico are likely impacted. We estimate the potential negative economic effects of this blow out and oil spill on commercial and recreational fishing, as well as mariculture (marine aquaculture) in the U.S. Gulf area, by computing potential losses throughout the fish value chain. We find that the spill could, in the next seven years, result in (midpoint) present value losses of total revenues, total profits, wages, and economic impact of US$3.7, $1.9, $1.2, and $8.7 billion, respectively. Commercial and recreational fisheries would likely suffer most losses, with an estimated US$1.6 and US$1.9 billion of total revenue loss, US$0.8 and 1.1 billion in total profit, and US$4.9 and US$3.5 billion of total economic impact for commercial and recreational fisheries, respectively.

47. **Benefits of Rebuilding Global Marine Fisheries Outweigh Costs.**

U. R. Sumaila, W. Cheung, A. Dyck, K. Gueye, L. Huang, V. Lam, D. Pauly, U. Srinivasan, W. Swartz, R. Watson, D. Zeller, (2012). *PLoS One* 7,

global fisheries; marine; rebuilding; costs

10.1371/journal.pone.0040542, http://www.ecomarres.com/downloads/Benefits.pdf

Global marine fisheries are currently underperforming, largely due to overfishing. An analysis of global databases finds that resource rent net of subsidies from rebuilt world fisheries could increase from the current negative US$13 billion to positive US$54 billion per year, resulting in a net gain of US$600 to US$1,400 billion in present value over fifty years after rebuilding. To realize this gain, governments need to implement a rebuilding program at a cost of about US$203 (US$130–US$292) billion in present value. We estimate that it would take just 12 years after rebuilding begins for the benefits to surpass the cost. Even without accounting for the potential boost to recreational fisheries, and ignoring ancillary and non-market values that would likely increase, the potential benefits of rebuilding global fisheries far outweigh the costs.

48. **Global Fisheries Losses at the Exclusive Economic Zone Level, 1950 to Present**

U. T. Srinivasan, R. Watson, U. R. Sumaila, (2012). *Marine Policy* 36, 544-549.

overfishing; fisheries management; depletion; sustainability

10.1016/j.marpol.2011.10.001, http://www.ecomarres.com/downloads/Loss3.pdf

Up to one-third of commercial fishery stocks maybe overfished at present. By analyzing catch trends and applying an empirical relationship derived from stock assessments, this article tracks the geographic spread of overfishing at the country level in terms of lost catch and lost revenue, from the start of industrialized fishing in 1950–2004The results tell a cautionary tale of serial depletion to meet the ever-rising demand for fish. Examining country losses with respect to fishery management reveals that overcapacity and excess fishing effort are widespread, but also that recent trends towards sustainability can stabilize or reverse losses(e.g. for Norway, Iceland, the US, Canada, Australia, and New Zealand). Global trade effectively masks the successive depletion of stocks, so that without decisive action to reduce fishing effort, many more stocks will suffer and undernourishment impacts for the major exporting, food-deficit nations will only magnify.

49. **Sustainability of Deep-Sea Fisheries**

E. A. Norse, S. Brooke, W. W. L. Cheung, M. R. Clark, I. Ekeland, R. Froese, K. M. Gjerde, R. L. Haedrich, S. S. Heppell, T. Morato, L. E. Morgan, D. Pauly, R. Sumaila, R. Watson, (2012). *Marine Policy* 36, 307-320.

sustainability; deep-sea fisheries; fisheries collapse; fisheries economics; high seas; global fisheries

10.1016/j.marpol.2011.06.008, http://www.ecomarres.com/downloads/deepsea.pdf

As coastal fisheries around the world have collapsed, industrial fishing has spread seaward and deeper in pursuit of the last economically attractive concentrations of fishable biomass. For a seafood-hungry world depending on the oceans' ecosystem services, it is crucial to know whether deep-sea fisheries can be sustainable. The deepsea is by far the largest but least productive part of the oceans, although in very limited places fish biomass can be very high. Most deep-sea fishes have life histories giving them far less population resilience/productivity than shallow-water fishes, and could be fished sustainably only at very low catch rates if population resilience were the sole consideration. But like old-growth trees and great whales, their biomass makes them tempting targets while their low productivity creates strong economic incentive to liquidate their populations rather than exploiting them sustainably (Clark'sLaw). Many deep-sea fisheries use bottom trawls, which often have high impacts on nontarget fishes (e.g., sharks) and invertebrates (e.g.,corals), and can often proceed only because they receive massive government subsidies. The combination of very low target population productivity, nonselectivefishing gear, economics that favor population liquidation and a very weak regulatory regime makes deep-sea fisheries unsustainable with very few exceptions. Rather, deep-sea fisheries more closely resemble mining operations that serially eliminate fishable populations and moveon. Instead of mining fish from the least-suitable places on Earth, an ecologically and economically preferable strategy would be rebuilding and sustainably fishing resilient populations in the most suitable places, namely shallower and more productive marine ecosystems that are closer to markets.

50. **The Mediterranean Sea under Siege: Spatial Overlap between Marine Biodiversity, Cumulative Threats and Marine Reserves**

M. Coll, C. Piroddi, C. Albouy, F. Ben Rais Lasram, W. W. L. Cheung, V. Christensen, V. S. Karpouzi, F. Guilhaumon, D. Mouillot, M. Paleczny, M. L. Palomares, J. Steenbeek, P. Trujillo, R. Watson, D. Pauly, (2012). *Global Ecology and Biogeography* 21, 465-480.

cumulative impacts; human threats; marine biodiversity; marine conservation; marine protected areas; MPA; Mediterranean Sea

10.1111/j.1466-8238.2011.00697.x, http://www.ecomarres.com/downloads/Med2Coll.pdf

Our results show that areas with high marine biodiversity in the Mediterranean Sea are mainly located along the central and north shores, with lower values in the south-eastern regions. Areas of potential high cumulative threats are widespread in both the western and eastern basins, with fewer areas located in the south-eastern region. The interaction between areas of high biodiversity and threats for invertebrates, fishes and large animals in general (including large fishes, marine mammals, marine turtles and seabirds) is concentrated in the coastal areas of Spain, Gulf of Lions, north-eastern Ligurian Sea, Adriatic Sea, Aegean Sea, south-eastern Turkey and regions surrounding the Nile Delta and north-west African coasts. Areas of concern are larger for marine mammal and seabird species.

51. **Shrinking of Fishes Exacerbates Impacts of Global Ocean Changes on Marine Ecosystems**

W. W. L. Cheung, J. L. Sarmiento, J. Dunne, T. L. Frölicher, V. W. Y. Lam, M. L. D. Palomares, R. Watson, D. Pauly, (2012). *Nature Climate Change*,

shrinkage; growth; climate change; global; marine ecosystems; ocean

10.1038/NCLIMATE1691, http://www.ecomarres.com/downloads/size.pdf

Changes in temperature, oxygen content and other ocean biogeochemical properties directly affect the ecophysiology of marine water-breathing organisms. Previous studies suggest that the most prominent biological responses are changes in distribution, phenology and productivity. Both theory and empirical observations also support the hypothesis that warming and reduced oxygen will reduce body size of marine fishes. However, the extent to which such changes would exacerbate the impacts of climate and ocean changes on global marine ecosystems remains unexplored. Here,we employ a model to examine the integrated biological responses of over 600 species of marine fishes due to changes in distribution, abundance and body size. The model has an explicit representation of ecophysiology, dispersal,

distribution, and population dynamics. We show that assemblage-averaged maximum body weight is expected to shrink by 14–24% globally from 2000 to 2050 under a high-emission scenario. About half of this shrinkage is due to change in distribution and abundance, the remainder to changes in physiology. The tropical and intermediate latitudinal areas will be heavily impacted, with an average reduction of more than 20%. Our results provide a new dimension to understanding the integrated impacts of climate change on marine ecosystems.

52. **Comparison of Marine Spatial Planning Methods in Madagascar Demonstrates Value of Alternative Approaches**

T. F. Allnutt, T. R. McClanahan, S. Andréfouët, M. Baker, E. Lagabrielle, C. McClennen, A. J. M. Rakotomanjaka, T. F. Tianarisoa, R. Watson, C. Kremen, (2012). *PloS one* 7, e28969.

marine spatial planning; Madagascar; MPA

10.1371/journal.pone.0028969, http://www.ecomarres.com/downloads/Madagascar.pdf

The Government of Madagascar plans to increase marine protected area coverage by over one million hectares. To assist this process, we compare four methods for marine spatial planning of Madagascar's west coast. Input data for each method was drawn from the same variables: fishing pressure, exposure to climate change, and biodiversity (habitats, species distributions, biological richness, and biodiversity value). The first method compares visual color classifications of primary variables, the second uses binary combinations of these variables to produce a categorical classification of management actions, the third is a target-based optimization using Marxan, and the fourth is conservation ranking with Zonation. We present results from each method, and compare the latter three approaches for spatial coverage, biodiversity representation, fishing cost and persistence probability. All results included large areas in the north, central, and southern parts of western Madagascar. Achieving 30% representation targets with Marxan required twice the fish catch loss than the categorical method. The categorical classification and Zonation do not consider targets for conservation features. However, when we reduced Marxan targets to 16.3%, matching the representation level of the "strict protection" class of the categorical result, the methods show similar catch losses. The management category portfolio has complete coverage, and presents several management recommendations including strict protection. Zonation produces rapid conservation rankings across large, diverse datasets. Marxan is useful for identifying strict protected areas that meet representation targets, and minimize exposure probabilities for conservation features at low economic cost. We show that methods based on Zonation and a simple combination of variables can produce results comparable to Marxan for species representation and catch losses, demonstrating the value of comparing alternative approaches during initial stages of the planning process. Choosing an appropriate approach ultimately depends on scientific and political factors including representation targets, likelihood of adoption, and persistence goals.

53. **Modelling the Effects of Fishing on the Biomass of the World's Oceans from 1950 to 2006**

L. Tremblay-Boyer, D. Gascuel, R. Watson, V. Christensen, D. Pauly, (2011). *Marine Ecology Progress Series* 442, 169-185.

ecosystem modelling; biomass; fisheries; marine predators; trophic level; global

10.3354/meps09375, http://www.ecomarres.com/downloads/biomass.pdf

Marine fisheries have endured for centuries but the last 50 years have seen a drastic increase in their reach and intensity. We generate global estimates of biomass for marine ecosystems and evaluate the effects that fisheries have had on ocean biomass since the 1950s. A simple but versatile ecosystem model was used to represent ecosystems as a function of energy fluxes through trophic levels. Using primary production data, sea surface temperature, transfer efficiency, fisheries catch and trophic level of species, the model was applied on a half-degree spatial grid covering all oceans. Estimates of biomass by trophic levels were derived for marine ecosystems in an unexploited state, as well as for all decades since the 1950s. Trends in the decline of marine biomass from the unexploited state were analyzed with a special emphasis on predator species since they are highly vulnerable to overexploitation. This study highlights three main trends about the global effects of fishing: (1) predators are more affected than organisms at lower trophic levels; (2) declines in ecosystem biomass are stronger along coastlines than in the High Seas; (3) the extent of fishing and its impacts have expanded from north temperate to equatorial and southern waters in the last 50 years. More specfically, this modelling work shows that many oceans historically exploited by humans have seen a drastic decline in their predator biomass, with about half of the coastal areas of the North Atlantic and North Pacific showing a decline in predator biomass of more than 90%.

54. **Potential Impact of the Deepwater Horizon Oil Spill on Commercial Fisheries in the Gulf of Mexico**

A. Scrub-McCrea, D. Zeller, U. R. Sumaila, W. Swartz, K. Kleisner, R. Watson, D. Pauly, (2011). *Fisheries* 36, 332-336.

oil spill; Gulf of Mexico; shrimp; closures

, http://www.ecomarres.com/downloads/Gulf.pdf

Given the economic and social importance of fisheries in the Gulf of Mexico large marine ecosystem (LME), it is imperative to quantify the potential impacts of the Deepwater Horizon oil spill. To provide a preliminary perspective of the consequences of this disaster, spatial databases of annual reported commercial catch and landed value prior to the spill were investigated relative to the location of the fisheries closures during July 2010. Recent trends illustrated by this study suggest that more than 20% of the average annual U.S. commercial catch in the Gulf has been affected by postspill fisheries closures, indicating a potential minimum loss in annual landed value of US$247 million. Lucrative shrimp, blue crab, menhaden, and oyster fisheries may be at greatest risk of economic losses. Overall, it is evident that the oil spill has impacted a highly productive area of crucial economic significance within the Gulf of Mexico LME. This study draws attention to the need for ongoing and thorough investigations into the economic impacts of the oil spill on Gulf fisheries.

55. **Protected and Threatened Components of Fish Biodiversity in the Mediterranean Sea.**

D. Mouillot, C. Albouy, F. Guilhaumon, F. Ben Rais Lasram, M. Coll, V. DeVictor, E. Douzery, C. Meynard, D. Pauly, J. A. Tomasini, M. Troussellier, L. Velez, R. Watson, N. Mouquet, (2011). *Current Biology* 21, 1044-1050.

Mediterranean; biodiversity; hot spots

10.1016/j.cub.2011.05.005, http://www.ecomarres.com/downloads/Med2.pdf

The Mediterranean Sea (0.82% of the global oceanic surface) holds 4%–18% of all known marine species (w17,000), with a high proportion of endemism [1, 2]. This exceptional biodiversity is under severe threats [1] but benefits from a system of 100 marine protected areas (MPAs). Surprisingly, the spatial congruence of fish biodiversity hot spots with this MPA system and the areas of high fishing pressure has not been assessed. Moreover, evolutionary and functional breadth of species assemblages [3] has been largely overlooked in marine systems. Here we adopted a multifaceted approach to biodiversity by considering the species richness of total, endemic, and threatened coastal fish assemblages as well as their functional and phylogenetic diversity. We show that these fish biodiversity components are spatially mismatched. The MPA system covers a small surface of the Mediterranean (0.4%) and is spatially congruent with the hot spots of all taxonomic components of fish diversity. However, it misses hot spots of functional and phylogenetic diversity. In addition, hot spots of endemic species richness and phylogenetic diversity are spatially congruent with hot spots of fishery impact. Our results highlight that future conservation strategies and assessment efficiency of current reserve systems will need to be revisited after deconstructing the different components of biodiversity.

56. **Construction and First Applications of a Global Cost of Fishing Database**

V. W. Y. Lam, U. R. Sumaila, A. Dyck, D. Pauly, R. Watson, (2011). *ICES Journal of Marine Science: Journal du Conseil* 68, 1996-2004.

catch; database; fisheries; fishing cost; fixed cost; fuel cost; global cost; sustainability; variable cost

10.1093/icesjms/fsr121, http://www.ecomarres.com/downloads/icesfishcost.pdf

The development of a new global database of fishing cost is described, and an overview of fishing cost patterns at national, regional, and global scales is provided. This fishing cost database provides economic information required for assessing the economics of fisheries at various scales. It covers variable and fixed costs of maritime countries, representing 98% of global landings in 2005. Linked to country and gear-type combinations, cost estimates can be mapped to a database of spatially allocated fisheries catches for future analysis in both spatial and temporal dimensions. The global average variable cost per tonne of catch in 2005 is estimated to range between US$639 and $1217, and the total cost per tonne from $763 to $1477, with mean values of $928 and $1120, respectively. The total global variable fishing cost is estimated to be in the range US$50–96 billion per year, with a mean of $73 billion per annum in 2005 dollar equivalents.

57. **High Value and Long Life—Double Jeopardy for Tunas and Billfishes**

B. B. Collette, K. E. Carpenter, B. A. Polidoro, M. J. Juan-Jordá, A. Boustany, D. J. Die, C. Elfes, W. Fox, J. Graves, L. Harrison, R. McManus, C. V. Minte-Vera, R. Nelson, V. Restrepo, J. Schratwieser, C. Sun, A. Amorim, M. B. Peres, C. Canale, G. Cardenas, S. Chang, W. Chiang, N. Leite, H. Harwell, R. Lessa, F. L. Fredou, H. A. Oxenford, R. Serra, K. Shao, R. Sumaila, S. Wang, R. Watson, E. Yáñez, (2011). *Science* 333, 291-292.

tuna; billfish; threat; global

10.1126/science.1208730, http://www.ecomarres.com/downloads/Tuna.pdf

We present here the first standardized data on the global distribution, abundance, population trends, and impact of major threats for all known species of scombrids and billfishes [see supporting online material (SOM) for details].

58. **Global Fishing Effort (1950–2010): Trends, Gaps, and Implications**

J. Anticamara, R. Watson, A. Gelchu, D. Pauly, (2011). *Fisheries Research* 107, 131-136.

fishing effort; global fishing; database; FAO; EU; CCAMLR

10.1016/j.fishres.2010.10.016, http://www.ecomarres.com/downloads/effort1.pdf

According to a recent World Bank report, the intensification of global fishing effort and the ensuing depletion of marine fish stocks causes economic losses of 50 billion US dollars annually. Data deficiencies, however, currently hamper analysis of global fishing effort. We analyzed data from the Food and Agricultural Organization of the United Nations (FAO), the EUROPA fishing fleet registry, and peer-reviewed and other publications, to determine the global trends in fishing effort from 1950 to 2006. Our results show that global fishing effort, expressed as total engine power and the number of fishing days in a year (kilowatt · days), was roughly constant from 1950 to 1970, and then steadily increased up to the present. Europe dominated global fishing effort, followed by Asia. Projecting current trends suggests that Asia will soon surpass Europe. Trawlers contribute a major fraction of global fishing effort, as do vessels greater than 100 gross registered tons. Current estimates of global fishing effort, the number of vessels, and total vessel tonnage are, however, underestimates given the data gaps that we have identified. Our results are useful in the following ways: (1) they encourage researchers in academia and government to improve global fishing effort databases; (2) they allow deeper global analyses of the impact of fishing on marine ecosystems; (3) they induce caution in accepting current underestimates of economic losses of global fisheries; and (4) they reinforce calls for a reduction in global fishing effort.

59. **Rapid Global Expansion of Invertebrate Fisheries: Trends, Drivers, and Ecosystem Effects**

S. C. Anderson, J. M. Flemming, R. Watson, H. K. Lotze, (2011). *PloS one* 6, e14735.

invertebrate; fisheries; global; ecosystem

10.1371/journal.pone.001473, http://www.ecomarres.com/downloads/Invert.pdf

Worldwide, finfish fisheries are receiving increasing assessment and regulation, slowly leading to more sustainable exploitation and rebuilding. In their wake, invertebrate fisheries are rapidly expanding with little scientific scrutiny despite increasing socio-economic importance.

60. **Serial Exploitation of Global Sea Cucumber Fisheries**

S. C. Anderson, J. M. Flemming, R. Watson, H. K. Lotze, (2011). *Fish and Fisheries* 12, 317-339.

beche-de-mer; seacucumber; echinoderms; global market; invertebrate fisheries; global fisheries

10.1111/j.1467-2979.2010.00397.x, http://www.ecomarres.com/downloads/seacuc.pdf

In recent decades, invertebrate fisheries have expanded in catch and value worldwide. One increasingly harvested group is sea cucumbers (class Holothuroidea), which are highly valued in Asia and sold as trepang or beˆche-de-mer. We compiled global landings, economic data, and country-specific assessment and management reports to synthesize global trends in sea cucumber fisheries, evaluate potential drivers, and test for local and global serial exploitation patterns. Although some sea cucumber fisheries have existed for centuries, catch trends of most individual fisheries followed boom-and-bust patterns since the 1950s, declining nearly as quickly as they expanded. New fisheries expanded five to six times faster in 1990 compared to 1960 and at an increasing distance from Asia, encompassing a global fishery by the 1990s. Global sea cucumber production was correlated to the Japanese yen at a leading lag. Regional assessments revealed that population declines from overfishing occurred in 81% of sea cucumber fisheries, average harvested body size declined in 35%, harvesters moved from near- to off-shore regions in 51% and from high- to low-value species in 76%. Thirty-eight per cent of sea cucumber fisheries remained unregulated, and illegal catches were of concern in half. Our results suggest that development patterns of sea cucumber fisheries are largely predictable, often unsustainable and frequently too rapid for effective management responses. We discuss potential ecosystem and human community consequences and urge for better monitoring and reporting of catch and abundance, proper scientific stock assessment and consideration of international trade regulations to ensure long-term and sustainable harvesting of sea cucumbers worldwide.

61. **The Spatial Expansion and Ecological Footprint of Fisheries (1950 to Present)**

W. Swartz, E. Sala, S. Tracey, R. Watson, D. Pauly, (2010). *PloS one* 5, e15143.

global fisheries; marine fisheries; primary production; sustainability; human footprint

10.1371/journal.pone.001514, http://www.ecomarres.com/downloads/expansion.pdf

Using estimates of the primary production required (PPR) to support fisheries catches (a measure of the footprint of fishing), we analyzed the geographical expansion of the global marine fisheries from 1950 to 2005. We used multiple threshold levels of PPR as percentage of local primary production to define 'fisheries exploitation' and applied them to the global dataset of spatially-explicit marine fisheries catches. This approach enabled us to assign exploitation status across a 0.5 latitude/longitude ocean grid system and trace the change in their status over the 56-year time period. This result highlights the global scale expansion in marine fisheries, from the coastal waters off North Atlantic and West Pacific to the waters in the Southern Hemisphere and into the high seas. The southward expansion of fisheries occurred at a rate of almost one degree latitude per year, with the greatest period of expansion occurring in the 1980s and early 1990s. By the mid 1990s, a third of the world's ocean, and two-third of continental shelves, were exploited at a level where PPR of fisheries exceed 10% of PP, leaving only unproductive waters of high seas, and relatively inaccessible waters in the Arctic and Antarctic as the last remaining 'frontiers.' The growth in marine fisheries catches for more than half a century was only made possible through exploitation of new fishing grounds. Their rapidly diminishing number indicates a global limit to growth and highlights the urgent need for a transition to sustainable fishing through reduction of PPR.

62. **Sourcing Seafood for the Three Major Markets: The Eu, Japan and the USA**

W. Swartz, U. Rashid Sumaila, R. Watson, D. Pauly, (2010). *Marine Policy* 34, 1366-1373.

seafood consumption; global fisheries; international trade; sustainability; Japan; USA; EU; markets

10.1016/j.marpol.2010.06.011, http://www.ecomarres.com/downloads/Swartz2.pdf

This paper describes the marine fish and invertebrate consumption in three of the world's major seafood markets (the EU, Japan and the USA)using a series of global maps indicating the likely origin of the seafood consumed by each market. These maps display a high level of dependence by these markets on foreign sources as the serial depletion of local fisheries resources forced the fleets in search for new seafood supplies well beyond their domestic waters. The acquisition of foreign(and highseas) seafood by these markets is conducted through two channels: by dispatching distant water fishing fleets that directly exploit foreign stocks; and by importing catch landed elsewhere by local fleets. The results also demonstrate that each of the three major markets occupies a zone of influence within which it is dominant.

63. **A Bottom-up Re-Estimation of Global Fisheries Subsidies**

U. R. Sumaila, A. S. Khan, A. J. Dyck, R. Watson, G. Munro, P. Tydemers, D. Pauly, (2010). *Journal of Bioeconomics* 12, 201-225.

subsidies; global fisheries; value

10.1007/s10818-010-9091-8, http://www.ecomarres.com/downloads/bioeco2.pdf

Using a recently developed database of fisheries subsidies for 148 maritime countries spanning 1989 to the present, total fisheries subsidies for the year 2003 is computed. A key feature of our estimation approach is that it explicitly deals with missing data from official sources, and includes estimates of subsidies to developing country fisheries. Our analysis suggests that global fisheries subsidies for 2003 are between US$ 25 and 29 billion, which is higher than an earlier World Bank estimate of between US$ 14–20 billion. This new estimate is lower than our 2000 global subsidies estimate of US$ 30–34 billion.We find that fuel subsidies compose about 15–30% of total global fishing subsidies, and that capacity enhancing subsidies sum to US$ 16 billion or about 60% of the total. These results imply that the global community is paying.

64. **Subsidies to High Seas Bottom Trawl Fleets and the Sustainability of Deep-Sea Demersal Fish Stocks**

U. R. Sumaila, A. Khan, L. Teh, R. Watson, P. Tyedmers, D. Pauly, (2010). *Marine Policy* 34, 495-497.

subsidies; high seas; deep-sea fisheries; sustainability

10.1016/j.marpol.2009.10.004, http://www.ecomarres.com/downloads/subsid3.pdf

The life spans of demersal species of fishes occurring in deepwaters are much longer and their potential growth rates much lower than those of related shallow water species. As a result, deep-sea demersal fish species are more vulnerable to exploitation. This is because low growth rates relative to the available market discount rate for capital makes it desirable for fishing firms to mine, rather than sustainably exploit, these resources even in the absence of fisheries subsidies. However, it is common knowledge that governments around the world do provide subsidies to their fishing industries. The objective of this contribution is to estimate the global amount of subsidies paid to bottom trawl fleets operating in the highseas, i.e., outside of the Exclusive Economic Zones of maritime countries. Our study suggests that fisheries subsidies to these fleets stand at about US$ 152million per year, which constitutes 25%of the total landed value of the fleet. Economic data for bottom trawlers suggest that the profit achieved by this vessel group is normally not more than 10%of landed value. The implication of this finding is that without subsidies, the bulk of the world's bottom trawl fleet operating in the high seas will be operating at a loss, and unable to fish, thereby reducing the current threat to deep-sea and high seas fish stocks.

65. **Food Security Implications of Global Marine Catch Losses Due to Overfishing**

U. T. Srinivasan, W. W. L. Cheung, R. Watson, U. R. Sumaila, (2010). *Journal of Bioeconomics* 12, 183-200.

value loss; protein; nourishment; global

10.1007/s10818-010-9090-9, http://www.ecomarres.com/downloads/Thara2.pdf

Excess fishing capacity and the growth in global demand for fishery products have made overfishing ubiquitous in the world's oceans. Here we describe the potential catch losses due to unsustainable fishing in all countries' exclusive economic zones (EEZs) and on the high seas over 1950-2004. To do so, we relied upon catch and price statistics from the Sea Around Us Project as well as an empirical relationship we derived from species stock assessments by the U.S. National Oceanic and Atmospheric Administration. In 2000 alone, estimated global catch losses amounted to 7-36% of the actual tonnage landed that year, resulting in a landed value loss of between $6.4 and 36 billion (in 2004 constant US$). From 1950-2004, 36-53% of commercial species in 55-66% of EEZs may have been overfished. Referring to a species-level database of intrinsic vulnerability (V) based on life-history traits, it appears that susceptible species were depleted quickly and serially, with the average V of potential catch losses declining at a similar rate to that of actual landings. The three continental regions to incur greatest losses by mass were Europe, North America, and Asia—forming a geographic progression in time. But low-income and small island nations, heavily dependent on marine resources for protein, were impacted most profoundly. Our analysis shows that without the inexorable march of overfishing, ~20 million people worldwide could have averted undernourishment in 2000. For the same year, total catch in the waters of low-income food deficit nations might have been up to 17% greater than the tonnage actually landed there. The situation may be worst for Africa, which in our analysis registered losses of about 9-49% of its actual catches by mass in year 2000, thus seriously threatening progress towards the UN Millennium Development Goals.

66. **Global Fishery Development Patterns Are Driven by Profit but Not Trophic Level**

S. A. Sethi, T. A. Branch, R. Watson, (2010). *Proceedings of the National Academy of Sciences* 107, 12163-12167.

fishing; harvest; management; business; trophic level

10.1073/pnas.1003236107, http://www.ecomarres.com/downloads/PNAS27.pdf

Successful ocean management need consider not only fishing impacts, but drivers of harvest. Consolidating post-1950 global catch and economic data, we assess which attributes of fisheries are good indicators for fishery development. Surprisingly, year of development and economic value are not correlated with fishery trophic levels. Instead, patterns emerge of profit-driven fishing for attributes related to costs and revenues. Fisheries initially developed on shallow ranging species with large catch, high price, and big body size, and then expanded to less desirable species. Revenues expected from developed fisheries declined 95% during 1951-1999, and few high catch or valuable fishing opportunities remain. These results highlight the importance of economic attributes of species as leading indicators for harvest-related impacts in ocean ecosystems.

67. **Seamount Fisheries: Do They Have a Future?**

T. N. J. Pitcher, M. R. Clark, T. Morato, R. Watson, (2010). *Oceanography* 23, 134.

seamount; fisheries; trawling

1042-8275, http://www.ecomarres.com/downloads/Oceanography.pdf

Today, seamount fish populations are in trouble following a 30-year history of overexploitation, depletion, and collapse, with untold consequences for global biodiversity and the complex, delicate, but poorly understood, open-ocean food webs. Seamount fishes are especially vulnerable to fishing because their "boomand-bust" life history characteristics can be exploited by heavy, high-technology fisheries. We estimate present global seamount catches to be about 3 million tonnes per annum and increasing—vastly in excess of estimated sustainable levels. Unfortunately, most seamount fisheries are unmanaged. In a few developed countries, precautionary management regimes have recently been introduced, including protection from bottom trawling. Small-scale artisanal fisheries using less-harmful fishing gear, patial closures, and low catch levels provide an attractive model for improved seamount fishery management that could foster the reconstruction of previously damaged seamount ecosystems. Such restored systems might one day support a

substantial global sustainable fishery, although, like many other fisheries, the prognosis is poor.

68. **The Contribution of Cephalopods to Global Marine Fisheries: Can We Have Our Squid and Eat Them Too?**

M. E. Hunsicker, T. E. Essington, R. Watson, U. R. Sumaila, (2010). *Fish and fisheries* 11, 421-438.

cephalopod; invertebrates; global; marine; fisheries

10.1111/j.1467-2979.2010.00369.x, http://www.ecomarres.com/downloads/Ceph.pdf

Cephalopods are a key component of marine food webs, providing sustenance for myriad marine species. Cephalopods are also of increasing economic importance as evidenced by the rapid rise in their global landings over recent decades. If fisheries continue on this trajectory, conflicts may transpire among cephalopod and finfish fisheries, particularly in ecosystems where cephalopods are highly valuable both directly as a landed commodity and indirectly as prey for other harvested species. We provide the first measure of the ecosystem services that cephalopods contribute to fisheries in 28 marine ecosystems, both as a commodity and an ecological support service. We also evaluate how current demands on cephalopods compare to mid-20th century conditions. We find that cephalopod contributions to fisheries vary widely, but are substantial in many ecosystems. Commodity and supportive services provided by cephalopods contributed as much as 55% of fishery landings (tonnes) and 70% of landed values ($USD). The contribution of cephalopods as a commodity was generally greatest in the coastal ecosystems, whereas their contribution as a supportive service was highest in open ocean systems. Further, the commodity and supportive services provided by cephalopods to fisheries landings increased in most of the coastal ecosystems between the mid-20th century (years 1960–70) and contemporary periods (years 1990–2004), indicating the rising demand for cephalopods. Current demands have no historical precedent and ecosystems in which cephalopods are highly exploited as a targeted resource and as an ecological support service should be further evaluated to prevent the unsustainable development of marine fisheries within them.

69. **Large−Scale Redistribution of Maximum Fisheries Catch Potential in the Global Ocean under Climate Change**

W. W. L. Cheung, V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, D. Zeller, D. Pauly, (2010). *Global Change Biology* 16, 24-35.

climate change; global; marine; fisheries; catch redistribution; potential

10.1111/j.1365-2486.2009.01995.x, http://www.ecomarres.com/downloads/GC.pdf

Previous projection of climate change impacts on global food supply focuses solely on production from terrestrial biomes, ignoring the large contribution of animal protein from marine capture fisheries. Here, we project changes in global catch potential for 1,066 species of exploited marine fish and invertebrates from 2005 to 2055 under climate change scenarios. We show that climate change may lead to large scale re-distribution of global catch potential, with an average of 30 - 70% increase in high latitude regions and a drop of up to 40% in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semi-enclosed seas while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean. Among the 20 most important fishing Exclusive Economic Zone (EEZ) regions in terms of their total landings, EEZ regions with the highest increase in catch potential by 2055 include Norway, Greenland, US (Alaska) and Russia (Asia). On the contrary, EEZ regions with the biggest loss in maximum catch potential include Indonesia, USA (excluding Alaska and Hawaii), Chile, and China. Many highly impacted regions, particularly those in the tropics, are socio-economically vulnerable to these changes. 36 Thus, our results indicate the need to develop adaptation policy that could minimize climate change impacts through fisheries. The study also provides information which may be useful to evaluate fisheries management options under climate change.

70. **Global Marine Primary Production Constrains Fisheries Catches**

E. Chassot, S. Bonhommeau, N. K. Dulvy, F. Mélin, R. Watson, D. Gascuel, O. Le Pape, (2010). *Ecology Letters* 13, 495-505.

fisheries; bottom-up; Large Marine Ecosystem; LME; transfer efficiency

10.1111/j.1461-0248.2010.01443.x, http://www.ecomarres.com/downloads/EL.pdf

Primary production must constrain the amount of fish and invertebrates available to expanding fisheries; however the degree of limitation has only been demonstrated at regional scales to date. Here we show that phytoplanktonic primary production, estimated from an ocean-color satellite (SeaWiFS), is related to global fisheries catches at the scale of Large Marine Ecosystems, while accounting for temperature and ecological factors such as ecosystem size and type, species richness, animal body size, and the degree and nature of fisheries exploitation. Indeed we show that global fisheries catch since 1950 have been increasingly constrained by the amount of primary production. The primary production appropriated by current global fisheries is 17 to 112% higher than that appropriated by sustainable fisheries. Global primary production appears to be declining, in some part due to climate variability and change, with consequences for the near future fisheries catches.

71. **Global Biodiversity: Indicators of Recent Declines**

S. H. M. Butchart, W. Walpole, B. Collen, A. van Strien, R. E. A. Almond, J. E. M. Baillie, B. Bomhard, C. Brown, J. Bruno, G. M. Carr, A. Chenery, J. Csirke, N. C. Davidson, M. Foster, A. Galli, J. N. Galloway, P. Genovesi, R. Gregory, M. Hockings, V. Kapos, J. Lamarque, F. Leverington, J. Loh, M. A. McGeoch, L. McRae, A. Minasyan, M. H. Morcillo, T. Oldfield, D. Pauly, S. Quader, C. Revenga, J. Sauer, J. P. W. Scharlemann, B. Skolnik, D. Spear, D. Stanwell-Smith, A. Symes, M. Tierney, T. R. Tyrrell, J. Vié, R. Watson, (2010). *Science* 328, 1164-1168.

global; biodiversity; marine

10.1126/science.1187512, http://www.ecomarres.com/downloads/biodiversity.pdf

In 2002, world leaders committed through the Convention on Biological Diversity (CBD) to achieve a significant reduction in the rate of biodiversity loss by 2010. We compiled 31 indicators to report on progress toward this target. Most indicators of the state of biodiversity (covering species' population trends, extinction risk, habitat extent/condition, and community composition) showed declines, with no significant recent reductions inrate, whereas indicators of pressures on biodiversity (including resource consumption, invasive alien species, nitrogen pollution, over-exploitation, and climate change impacts) showed increases. Despite some local successes and increasing responses (including extent and biodiversity coverage of protected areas, sustainable forest management, policy responses to invasive alien species, and biodiversity-related aid), the rate of biodiversity loss does not appear to be slowing.

72. **Effects of Climate−Driven Primary Production Change on Marine Food Webs: Implications for Fisheries and Conservation**

C. J. Brown, E. A. Fulton, A. J. Hobday, R. Matear, H. Possingham, C. Bulman, V. Christensen, R. Forrest, P. Gehrke, N. Gribble, S. Griffiths, S. H. Lozano-Montes, J. Martin, S. Metcalf, T. Okey, R. Watson, A. J. Richardson, (2010). *Global Change Biology* 16, 1194-1212.

climate change; marine; ecosystem modelling; Ecopath

10.1111/j.1365-2486.2009.02046.x, http://www.ecomarres.com/downloads/GC2.pdf

Climate change is altering the rate and distribution of primary productivity in the world's oceans. Predicting effects of changes in primary production on marine ecosystems and fisheries will assist the conservation of marine biodiversity and the sustainable management of fisheries. However, predicting the response of populations to primary production change is difficult, because inter-specific interactions can influence outcomes. We simulated the effects of change in primary production on Australian marine ecosystems across a wide latitudinal range using the marine food web model called 'Ecosim'. We link models of primary production under climate change with Ecosim to predict changes in fishery catch, fishery value, abundance of animals of conservation interest, and indicators of community composition. Under a plausible climate change scenario, primary production will increase around Australia and generally this benefits fisheries catch and value and abundance of threatened marine animals such as turtles and sharks, but surprisingly, community composition was not strongly affected. However, ecological interactions reverse the expected responses for some populations, resulting in loss of value for some specific fisheries and localised declines for two threatened marine animal populations. We conclude that climate-driven primary production change should be considered by marine ecosystem managers and production increases can simultaneously benefit fisheries and conservation of biodiversity. Greater focus on incorporating biological interactions into management will significantly improve the ability to identify species and industries most at risk from climate change.

73. **The Trophic Fingerprint of Marine Fisheries**

T. A. Branch, R. Watson, E. A. Fulton, S. Jennings, C. R. McGilliard, G. T. Pablico, D. Ricard, S. R. Tracey, (2010). *Nature* 468, 431-435.

Marine Trophic Index; trophic level; global marine; catch; ecosystems

10.1038/nature09528, http://www.ecomarres.com/downloads/Fingerprint.pdf

Biodiversity indicators provide a vital window on the state of the planet, guiding policy development and management. The most widely adopted marine indicator is mean trophic level (MTL) from catches, intended to detect shifts from high-trophic-level predators to low-trophic-level invertebrates and plankton-feeders. This indicator underpins reported trends in human impacts, declining when predators collapse (“fishing down marine food webs”) and when low-trophic-level fisheries expand (“fishing through marine food webs”). The assumption is that catch MTL measures changes in ecosystem MTL and biodiversity. Here we combine model predictions with global assessments of MTL from catches, trawl surveys and fisheries stock assessments and find that catch MTL does not reliably predict changes in marine ecosystems. Instead, catch MTL trends often diverge from ecosystem MTL trends obtained from surveys and assessments. In contrast to previous findings of rapid declines in catch MTL, we observe recent increases in catch, survey and assessment MTL. However, catches from most trophic levels are rising, which can intensify fishery collapses even when MTL trends are stable or increasing. To detect fishing impacts on marine biodiversity, we recommend greater efforts to measure true abundance trends for marine species, especially those most vulnerable to fishing.

74. **Aggregate Performance in Managing Marine Ecosystems of 53 Maritime Countries**

J. Alder, S. Cullis-Suzuki, V. Karpouzi, K. Kaschner, S. Mondoux, W. Swartz, P. Trujillo, R. Watson, D. Pauly, (2010). *Marine Policy* 34, 468-476.

environmental indicator; fisheries; sustainability; mariculture; aquculture; marine mammal; seabird

10.1016/j.marpol.2009.10.001, http://www.ecomarres.com/downloads/Rankings.pdf

Fourteen indicators of marine living resource management performance by country, reflecting both their intention to sustainably use the resource within their Exclusive Economic Zones and the effectiveness of their policies, were developed and the performances of 53 maritime countries were assessed. Four rankings of the countries, which jointly account for over 95 percent of the world’s marine fisheries landings, are presented here as aggregated scores of the fourteen indicators, using differentschemes for weighting the indicators, each reflective of the management preferences identified by the Global Environment Outlook 4 (GEO4) future development scenarios: Market First; Policy First; Security First; and Sustainability First. The resulting rankings differed substantially between the weighting schemes for the top performing countries but less so for the countries performing poorly.

75. **Rebuilding Global Fisheries**

B. Worm, R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. J. Lotze, P. M. Mace, T. A. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, D. Zeller, (2009). *Science* 325, 578-585.

fisheries; global; management; recovery; collapse; LME

10.1126/science.1173146, http://www.ecomarres.com/downloads/rebuild.pdf

After a long history of overexploitation, increasing efforts to restore marine ecosystems and rebuild fisheries are under way. Here, we analyze current trends from a fisheries and conservation perspective. In 5 of 10 well-studied ecosystems, the average exploitation rate has recently declined and is now at or below the rate predicted to achieve maximum sustainable yield for seven systems. Yet 63% of assessed fish stocks worldwide still require rebuilding, and even lower exploitation rates are needed to reverse the collapse of vulnerable species. Combined fisheries and conservation objectives can be achieved by merging diverse management actions, including catch restrictions, gear modification, and closed areas, depending on local context. Impacts of international fleets and the lack of alternatives to fishing complicate prospects for rebuilding fisheries in many poorer regions, highlighting the need for a global perspective on rebuilding marine resources.

76. **Management Effectiveness of the World's Marine Fisheries.**

C. Mora, R. A. Myers, T. J. Pitcher, C. De Young, R. Sumaila, D. Zeller, R. Watson, F. J. Gaston, B. Worm, (2009). *PLoS Biology* 7, e1000131.

fisheries; global; management; sustainability

101371/journal.pbio.1000131, http://www.ecomarres.com/downloads/Management.pdf

Ongoing declines in production of the world's fisheries may have serious ecological and socioeconomic consequences. As a result, a number of international efforts have sought to improve management and prevent overexploitation, while helping to maintain biodiversity and a sustainable food supply. Although these initiatives have received broad acceptance, the extent to which corrective measures have been implemented and are effective remains largely unknown. We used a survey approach, validated with empirical data, and enquiries to over 13,000 fisheries experts to assess the current effectiveness of fisheries management regimes worldwide; for each of those regimes we also calculated the probable sustainability of reported catches to determine how management affects fisheries sustainability. Our survey shows that 7% of all coastal states undergo rigorous scientific assessment for the generation of management policies, 1.4% also have a participatory and transparent processes to convert scientific recommendations into policy and 0.95% also provide for robust mechanisms to ensure the compliance with regulations; none is also free of the effects of excess fishing capacity, subsidies or access to foreign fishing. A comparison of 2 fisheries management attributes with the sustainability of reported fisheries catches indicated that the conversion of scientific advice into policy, through a participatory and transparent process, is at the core of achieving fisheries sustainability, regardless of other attributes of the fisheries. Our results illustrate the great vulnerability of the world's fisheries and the urgent need to meet wellidentified guidelines for sustainable management; they also provide a baseline against which future changes can be quantified.

77. **Database-Driven Models of the World's Large Marine Ecosystems.**

V. Christensen, C. Walters, R. Ahrens, J. Alder, J. Buszowski, L. B. Christensen, W. Cheung, J. Dunne, R. Froese, V. Karpouzi, K. Kaschner, K. Kearney, S. Lai, V. Lam, M. L. D. Palomares, A. Peters-Mason, C. Piroddi, J. L. Sarmiento, J. Steenbeek, R. Sumaila, R. Watson, D. Zeller, D. Pauly, (2009). *Ecological Modelling* 220, 1984-1996.

Ecopath; Ecosim; Ecosytem model; global model; LME; biomass

10.1016/j.ecolmodel.2009.04.041, http://www.ecomarres.com/downloads/DataModel.pdf

We present a newmethodology for database-driven ecosystem model generation and apply the methodology to the world's 66 currently defined Large Marine Ecosystems. Themethod relies on a largenumber of spatial and temporal databases, including FishBase, SeaLifeBase, as well as several other databases developed notably as part of the Sea Around Us project. The models are formulated using the freely available Ecopath with Ecosim (EwE) modeling approach and software. We tune the models by fitting to available time series data, but recognize that the models represent only a first-generation of database-driven ecosystem models.We use the models to obtain a first estimate of fish biomass in the world's LMEs. The biggest hurdles at present to further model development and validation are insufficient time series trend information, and data on spatial fishing effort.

78. **Projecting Global Marine Biodiversity Impacts under Climate Change Scenarios**

W. W. L. Cheung, V. W. Y. Lam, J. L. Sarmiento, K. Kearney, R. Watson, D. Pauly, (2009). *Fish and Fisheries* 10, 235-251.

bioclimate envelope; climate change impact; global marine biodiversity; niche-based model; species turnover

10.1111/j.1467-2979.2008.00315.x, http://www.ecomarres.com/downloads/FAF315.pdf

Climate change can impact the pattern of marine biodiversity through changes in species' distributions. However, global studies on climate change impacts on ocean biodiversity have not been performed so far. Our paper aims to investigate the global patterns of such impacts by projecting the distributional ranges of a sample of 1066 exploited marine fish and invertebrates for 2050 using a newly developed dynamic bioclimate envelope model. Our projections show that climate change may lead to numerous local extinction in the sub-polar regions, the tropics and semi-enclosed seas. Simultaneously, species invasion is projected to be most intense in the Arctic and the Southern Ocean. Together, they result in dramatic species turnovers of over 60% of the present biodiversity, implying ecological disturbances that potentially disrupt ecosystem services. Our projections can be viewed as a set of hypothesis for future analytical and empirical studies.

79. **Estimating the Worldwide Extent of Illegal Fishing**

D. J. Agnew, J. Pearce, G. Pramod, T. Peatman, R. Watson, J. R. Beddington, T. J. Pitcher, (2009). *PLoS One* 4, e4570.

Illegal catch; IUU; global catch

10.1371/journal.pone.0004570, http://www.ecomarres.com/downloads/IUU1.pdf

Illegal and unreported fishing contributes to overexploitation of fish stocks and is a hindrance to the recovery of fish populations and ecosystems. This study is the first to undertake a world-wide analysis of illegal and unreported fishing. Reviewing the situation in 54 countries and on the high seas, we estimate that lower and upper estimates of the total value of current illegal and unreported fishing losses worldwide are between $10bn and $23.5bn annually, representing between 11 and 26 million tonnes. Our data are of sufficient resolution to detect regional differences in the level and trend of illegal fishing over the last 20 years, and we can report a significant correlation between governance and the level of illegal fishing. Developing countries are most at risk from illegal fishing, with total estimated catches in West Africa being 40% higher than reported catches. Such levels of exploitation severely hamper the sustainable management of marine ecosystems. Although there have been some successes in reducing the level of illegal fishing in some areas, these developments are relatively recent and follow growing international focus on the problem. This paper provides the baseline against which successful action to curb illegal fishing can be judged.

80. **Fuel Price Increase, Subsidies, Overcapacity, and Resource Sustainability**

U. R. Sumaila, L. Teh, R. Watson, P. Tyedmers, D. Pauly, (2008). *ICES Journal of Marine Science: Journal du Conseil* 65, 832-840.

subsidy; global fishing; fuel; price

10.1093/icesjms/fsn070, http://www.ecomarres.com/downloads/SumailaFuel.pdf

Global fisheries are currently overcapitalized, resulting in overfishing in many of the world's fisheries. Given that fuel constitutes a significant component of fishing costs, we expect recent increases in fuel prices to reduce overcapacity and overfishing. However, government fuel subsidies to the fishing sector reduce, if not completely negate, this positive aspect of increasing fuel costs. Here, we explore the theoretical basis for the expectation that the increasing fuel prices faced by fishing enterprises will reduce fishing pressure. Next, we estimate the amount of fuel subsidies to the fishing sector by governments globally to be in the range of US$4.2–8.5 billion per year. Hence, depending on how much of this subsidy existed before the recent fuel price increases, fishing enterprises, as a group, can absorb as much as this amount of increase in their fuel budget before any conservation benefits occur as a result of fuel price increases.

81. **The Debt of Nations and the Distribution of Ecological Impacts from Human Activities**

U. T. Srinivasan, S. P. Carey, E. Hallstein, P. A. T. Higgins, A. C. Kerr, L. E. Koteen, A. B. Smith, R. Watson, J. Harte, R. B. Norgaard, (2008). *Proceedings of the National Academy of Sciences* 105, 1768-1773.

global impacts; debt; biological impacts; over-fishing

10.1073 pnas.0709562104, http://www.ecomarres.com/downloads/PNAS1.pdf

As human impacts to the environment accelerate, disparities in the distribution of damages between rich and poor nations mount. Globally, environmental change is dramatically affecting the flow of ecosystem services, but the distribution of ecological damages and their driving forces have not been estimated previously. Here we give conservative, considerably partial estimates of the environmental costs of human activities over 1961-2000 in six major categories: climate change, stratospheric ozone depletion, agricultural intensification and expansion, deforestation, overfishing, and mangrove conversion. We calculate total costs ranging up to $47 trillion (net present value, 2005 international $), 92% of the year 2000 world GDP, purchasing power parity-adjusted. By quantitatively connecting the costs borne by rich, middle-income, and poor nations to activities by the three groups, we find striking imbalances. Up to 87% of the impacts of climate change and ozone depletion that are predicted to be borne by low-income nations have been directly driven by emissions from the middle- and high-income groups. Indeed, due to rich countries' disproportionate emissions of greenhouse gases, poor nations may bear climate impacts 68% more than their year 2000 foreign debt. In a world increasingly connected ecologically and economically, our analysis is an early step towards reframing issues of development, globalization, and international debt in accordance with true ecological costs.

82. **Response to Comment on" a Global Map of Human Impact on Marine Ecosystems"**

K. Selkoe, C. Kappel, B. Halpern, F. Micheli, C. D'Agrosa, J. Bruno, K. Casey, C. Ebert, H. Fox, R. Fujita, D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. Perry, E. Selig, M. Spalding, R. Steneck, S. Walbridge, R. Watson, (2008). *Science* 321, 1446c.

global; human threats; impacts; marine; mapping

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83. **A Global Map of Human Impact on Marine Ecosystems**

B. S. Halpern, S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. Bruno, K. Casey, C. Ebert, H. Fox, Fujita.R., D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. Perry, E. Selig, M. Spalding, R. Steneck, R. Watson, (2008). *Science* 319, 948-952.

mapping; global marine; ecosystems; human threats; impacts

10.1126/science.1149345, http://www.ecomarres.com/downloads/Halpernetal.pdf

Conservation prioritization and management of the oceans require spatially explicit information on how all types of human activities impact marine ecosystems, but methods for globally assessing such impacts and mapping their distribution have not previously existed. Using a novel ecosystem-specific and scale-independent model, we synthesized 17 global datasets on anthropogenic threats to 20 marine ecosystems. Results show that every part of the oceans is affected by humans and that a large fraction (34%) is heavily impacted, including both nearshore and offshore ecosystems in nearly every corner of the world. Although human impact on marine ecosystems is pervasive, areas of little impact remain, particularly near the poles. Our quantitative approach provides important guidelines for where conservation action and threat mitigation are most needed for achieving global management and conservation goals.

84. **Diminishing Sea Ice**

B. S. Halpern, C. V. Kappel, F. Micheli, K. A. Selkoe, C. D'Agrosa, J. Bruno, K. Casey, C. Ebert, H. Fox, Fujita.R., D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. Perry, E. Selig, M. Spalding, R. Steneck, S. Walbridge, R. Watson, (2008). *Science* 321,

mapping; global marine; ecosystems; human threats; impacts

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85. **Application of Macroecological Theory to Predict Effects of Climate Change on Global Fisheries Potential**

W. W. L. Cheung, C. Close, V. Lam, R. Watson, D. Pauly, (2008). *Marine Ecology Progress Series* 365, 187-197.

global warming; climate change; global fisheries; macroecology; range

10.3354/meps07414, http://www.ecomarres.com/downloads/cc1.pdf

Global changes are shaping the life history and biogeography of marine species, which then affects their fisheries. Macroecology theories, which deal with large scale relationships between life history and biogeography, can be used to develop models to predict effects of global changes on marine species and hence on their fisheries. Firstly, based on theories of allometric scaling of metabolism and trophic energetic, we develop a theoretical model that relates maximum catch potential from a species with its trophic level, geographic range, mean primary production within the species' range, and the fraction that is exploited at the geographic range. Secondly, using this theoretical model and data from 1,000 species of exploited marine fishes and invertebrates, we analyze the empirical relationship between species' approximated maximum catch potential, their life history, and biogeography variables. The empirical model has high explanatory power and agrees with expectations from theory. Although problems in the original data and the imprecision of model parameters result in high variance between the empirical model and the data, predictions of relative changes in catch potential under climate change-induced changes in biogeography should be robust to uncertainties. In the future, this empirical model can be combined with bioclimate envelope model to predict the socio-economic impacts of climate change on marine fisheries, and this is illustrated here with an example pertaining to the small yellow croaker (Larimichthys polyactis, Sciaendae) from the East China Sea.

86. **Potential Costs and Benefits of Marine Reserves in the High Seas**

U. R. Sumaila, D. Zeller, R. Watson, J. Alder, D. Pauly, (2007). *Marine Ecology Progress Series* 345, 305-310.

marine protected area; MPA; high seas; global; marine reserve

10.3354/meps07065, http://www.ecomarres.com/downloads/HighSeas.pdf

The issue of conservation and sustainable use of high seas resources is increasingly becoming significant, as is reflected in the number of planned international activities in ocean science and management, e.g. the United Nations General Assembly Working Group on marine biodiversity beyond national jurisdiction. Essentially, the increasing exploitation pressure on high and deep sea resources makes discussion of viable policy options for international waters an important topic. To our knowledge, this paper provides the first global, economically supported assessment of the impact on fisheries of potentially protecting a portion of the high seas in no-take marine protected areas. Such closures are likely to result in relatively little global annual profit loss. For example, closure of 20% of the high seas may lead to the loss of only 1.8% of the current global reported marine fisheries catch, and a decrease in profits to the high seas fleet of about US$270 million per year. Thus, at globally minimal costs, the international community could benefit substantially by securing insurance against extinctions and the loss of the spectacular marine diversity in the high and deep seas, while protecting many market and non-market values for the benefit of both current and future generations.

87. **A Global Ex-Vessel Fish Price Database: Construction and Applications**

U. R. Sumaila, A. D. Marsden, R. Watson, D. Pauly, (2007). *Journal of Bioeconomics* 9, 39-51.

landed values; catches; price; mapping; temporal applications

10.1007/s10818-007-9015-4, http://www.ecomarres.com/downloads/fishprice.pdf

We describe the first effort at creating a global ex-vessel fish price database, which is required for understanding the economic behaviour of participants in the world's fisheries. We demonstrate potential applications of the database by linking it to a spatially defined catch database, which makes it possible to attach landed values to species in both time and space. This is the first database available publicly where interested members of the public, researchers and managers can easily find and access ex-vessel prices of the world's major commercial fish species. Preliminary results indicate that the average real price of a number of species have declined between 1950 and 2002. The estimated landed value of fish globally, in year 2000 dollars, was about US$24 billion in 1950. It increased steadily to about US$90 billion in the early 1970s, reached a peak of US$100 billion at the end of the 1980s, and declined to about US$80 billion in 2000. The top 15 fishing countries cumulatively account for 79% of total real landed value, with Japan leading, even though the value of its landings has been declining.

88. **The World Trade Organization and Global Fisheries Sustainability**

U. R. Sumaila, A. Khan, R. Watson, G. Munro, D. Zeller, N. Baron, D. Pauly, (2007). *Fisheries Research* 88, 1-4.

subsidy; global fisheries; WTO

10.1016/j.fishres.2007.08.017, http://www.ecomarres.com/downloads/Subsidy2007.pdf

The World Trade Organization (WTO) is in a unique position to move global fisheries towards sustainability. The current Doha Trade Round of Negotiations offers an important opportunity to improve the future prospects of fish as a main source of animal protein for one fifth of the world's population. Countries are wrestling with the issue of government fisheries subsidies, which keep too many commercial fishing boats in operation and drive the unsustainable exploitation of the world's depleted fish populations. Removal of subsidies is challenging as it cannot be resolved without international cooperation because unilateral action has trade implications, and may not work because fish and fishing vessels do not respect national exclusive economic zones. This is why the WTO, which has in place mechanisms to enforce its agreements, is the only institution that can tackle the global problem of overfishing subsidies. We identify the opportunities and challenges that WTO members face, and provide suggestions on how to address these challenges.

89. **Modelling and Mapping Resource Overlap between Seabirds and Fisheries on a Global Scale: A Preliminary Assessment**

V. S. Karpouzi, R. Watson, D. Pauly, (2007). *CM-International Council for the Exploration of the Sea* 343, 87-99.

seabird – fisheries interactions; resource overlap; foraging distribution; seabird food consumption; seabird

10.3354/meps0686, http://www.ecomarres.com/downloads/Karpouzi_et_al_2007.pdf

Coexistence of foraging seabirds and operating fisheries may result in interactions such as competition for the same prey resources. We used GIS-based modelling at a scale of 30-min spatial cells to: (a) map the foraging distribution of seabirds; (b) predict their annual food consumption rates in a spatially-explicit manner; and (c) estimate a spatially-explicit seabird – fisheries overlap index. Information on population size, diet composition, and foraging attributes of

351 seabird species was compiled into a Microsoft Access database. Global annual food consumption by seabirds was estimated to be 96.4 million tonnes (95% CI: 78.0 to 114.7 million tonnes), compared to a total catch of nearly 120 million tonnes by all marine fisheries. Krill and cephalopods comprised over 58% of the overall food consumed and fishes most of the remainder. The families Procellariidae (albatrosses, petrels, shearwaters, etc.) and Spheniscidae (penguins) were responsible for over 54% of the overall food consumption. Seabird foraging distribution maps revealed that areas around New Zealand, the eastern Australian coast, and the sub-Antarctic islands had high species richness. However, temperate and polar regions supported high seabird densities, and most food extracted by seabirds originated there. Furthermore, maps of food consumption rates revealed that most food consumed by seabirds was extracted from offshore rather than nearshore waters, and from areas where seabird – fisheries overlap was low. The resource overlap maps identified 'hotspots' of highest potential for conflict between fisheries and seabirds. Thus, this study may provide useful insight when developing management approaches for designing offshore marine conservation areas.

90. **Intrinsic Vulnerability in the Global Fish Catch**

W. W. L. Cheung, R. Watson, T. Morato, T. J. Pitcher, D. Pauly, (2007). *Marine Ecology Progress Series* 333, 1-12.

global catch; threat; vulnerability

0171-8630, http://www.ecomarres.com/downloads/m333p001.pdf

We identify marine fishes most vulnerable to exploitation in different environments by comparing life history traits, represented by an index of intrinsic vulnerability. We then evaluate global changes in the mean vulnerability of catches comprising different species assemblages. Over the past 50 years, declines in mean vulnerability reveal increasing domination by low intrinsic vulnerability species. Coral reef fishes show the strongest decline, followed by seamount and estuarine assemblages: declines are most likely a result of rapid over-exploitation of highly vulnerable species. This is supported by a correlation between the spatial distributions of fishes listed under the IUCN Red List of Threatened Species and the rates of decline of mean vulnerability of catches. Fishes on the Red List are generally highly vulnerable. Deep water demersal and benthopelagic fishes, particularly those aggregated around seamounts, also have higher intrinsic vulnerability. These findings suggest that coral reef and seamount ecosystems potentially suffer high conservation risks from fishing. Moreover, concentrations of threatened fishes and strong declines in the mean vulnerability of catches in the Indo-Pacific and Caribbean highlight these regions for conservation attention.

91. **Impacts of Biodiversity Loss on Ocean Ecosystem Services**

B. Worm, E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz, R. Watson, (2006). *Science* 314, 787-790.

marine biodiversity; value; biodiversity; services; global

10.1126/science.1132294, http://www.ecomarres.com/downloads/biodiversityworm.pdf

Human-dominated marine ecosystems are experiencing accelerating loss of populations and species, with largely unknown consequences. We analyzed local experiments, longterm regional time series, and global fisheries data to test how biodiversity loss affects marine ecosystem services across temporal and spatial scales. Overall, rates of resource collapse increased, and recovery potential, stability, and water quality decreased exponentially with declining diversity. Restoration of iodiversity, in contrast, increased productivity four-fold and decreased variability by 21%, on average. We conclude that marine biodiversity loss is increasingly impairing the ocean's capacity to provide food, maintain water quality, and recover from perturbations. Yet, available data suggest that at this point these trends are still reversible.

92. **Fishing Gear Associated with Global Marine Catches: I Database Development.**

R. Watson, C. Revenga, Y. Kura, (2006). *Fisheries Research* 79, 97-102.

fishing gear; database; catch; trawl; dredge; purse seine

, http://www.ecomarres.com/downloads/gear1.pdf

Fishing gears, instrumental to the fishing process, can exert direct impacts on marine communities and habitats. The database described here allows for the analysis of global fishing patterns, by associating all reported global catch with fishing gear types. The fine spatial detail of the Sea Around Us project?s catch database allows for the construction of maps showing subtle changes in the use of fishing gears annually since 1950. Maps included in this report chronicle the expansion of these and other gears in ways that will inform the current debate over their impacts, and provide critical information to shape policy development and management choices.

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93. **Fishing Gear Associated with Global Marine Catches. Ii. Trends in Trawling and Dredging**

R. Watson, C. Revenga, Y. Kura, (2006). *Fisheries Research* 79, 103-111.

fishing gear; database; catch; trawl; dredge

, http://www.ecomarres.com/downloads/gear2.pdf

Fishing gears, instrumental to the fishing process, exert direct but often poorly documented impacts on marine communities and habitats. Analysis of global fishing patterns is now possible using a database that associates all global catch with fishing gear types. Maps prepared from this database are particularly useful to help assess the impact of fishing gears such as bottom trawls and dredges, which have been shown to have significant impacts on marine communities.

94. **Fishing Down the Deep**

T. Morato, R. Watson, T. J. Pitcher, D. Pauly, (2006). *Fish and Fisheries* 7, 24-34.

deep-sea; deep-water fisheries; threat; global trends; global

1467-2979, http://www.ecomarres.com/downloads/fishdeep.pdf

Global landings of demersal marine fishes are demonstrated to have shifted to deeper water species over the last 50 years. Our analysis suggests deep-water fish stocks may be at serious risk of depletion, as their life histories render them highly vulnerable to overfishing with little resilience to over-exploitation. Deep-sea fisheries are exploiting the last refuges for commercial fish species and should not be seen as a eplacement for declining resources in shallower waters. Instead, deep-water habitats are new candidates for conservation.

95. **Mapping World-Wide Distributions of Marine Mammal Species Using a Relative Environmental Suitability (Res) Model**

K. Kaschner, R. Watson, A. Trites, D. Pauly, (2006). *Marine Ecology Progress Series* 316, 285-310.

spatial modeling; habitat prediction; RES; habitat suitability

, http://www.ecomarres.com/downloads/whale1.pdf

We developed a large-scale habitat suitability modeling approach to map global distributions of 115 species of marine mammals. Predictions were generated by first assigning each species to broad-scale categories of habitat preferences with respect to depth, sea surface temperature and ice edge association based on synopses of published qualitative and quantitative habitat preference information. Using a global grid with 0.5 degree lat/long cell dimensions, we generated an index of the relative environmental suitability (RES) of each cell for a given species by relating quantified habitat preferences to locally averaged environmental conditions in a GIS modeling framework. RES predictions closely matched published maximum range extents for most species, suggesting that our model-based approach for identifying habitat represents a useful, more objective alternative to existing sketched distributional outlines. In addition, raster-based predictions provided more detailed information about heterogeneous patterns of potentially suitable habitat for species throughout their range. We validated RES model outputs for eleven species (northern fur seal, harbor porpoise, sperm whale, killer whale, hourglass dolphin, fin whale, humpback whale, blue whale and Antarctic minke whale) from a broad taxonomic and geographic range using at-sea sightings from dedicated surveys. Observed relative encounter rates and species-specific predicted environmental suitability were significantly and positively correlated for all, but one species. In comparison, observed encounter rates were correlated with < 1 % of 1000 simulated random data sets for all but two species. Mapping of suitable habitat for marine mammals using this environmental envelope model is helpful for evaluating current assumptions and knowledge about species? occurrences, especially for data-poor species. Moreover, RES modeling may help to focus research efforts on smaller geographic scales and usefully supplement other, statistical, habitat suitability models.

96. **Bioeconomic Modelling and Risk Assessment of Tiger Prawn (Penaeus Esculentus) Stock Enhancement in Exmouth Gulf, Australia**

Y. Ye, N. Loneragan, D. Die, R. Watson, B. Harch, (2005). *Fisheries research* 73, 231-249.

bioeconomic modelling; risk assessment; stock enhancement; tiger prawn; Penaeus esculentus; Australia

10.1016/j.fishres.2004.12.004, http://www.ecomarres.com/downloads/Exmouth.pdf

A bioeconomic model was developed to evaluate the potential performance of brown tiger prawn stock enhancement in Exmouth Gulf, Australia. This paper presents the framework for the bioeconomic model and risk assessment for all components of a stock enhancement operation, i.e. hatchery, grow-out, releasing, population dynamics, fishery, and monitoring, for a commercial scale enhancement of about 100 metric tonnes, a 25% increase in average annual catch in Exmouth Gulf. The model incorporates uncertainty in estimates of parameters by using a distribution for the parameter over a certain range, based on experiments, published data, or similar studies. Monte Carlo simulation was then used to quantify the effects of these uncertainties on the model-output and on the economic potential of a particular production target. The model incorporates density-dependent effects in the nursery grounds of brown tiger prawns. The results predict that a release of 21 million 1 g prawns would produce an estimated enhanced prawn catch of about 100 t. This scale of enhancement has a 66.5% chance of making a profit. The largest contributor to the overall uncertainty of the enhanced prawn catch was the post-release mortality, followed by the densitydependent mortality caused by released prawns. These two mortality rates are most difficult to estimate in practice and are much under-researched in stock enhancement.

97. **Catching Some Needed Attention**

R. Watson, J. Alder, A. Kitchingman, D. Pauly, (2005). *Marine Policy* 29, 281-284.

internet; catch; global

10.1016/j.marpol.2004.06.006, http://www.ecomarres.com/downloads/neededattention.pdf

Globally, the most basic need of policy makers and fisheries managers is to know what catch was taken within their jurisdictional boundaries, and which countries took it. Surprisingly, for many countries this has not been possible. We introduce a web site devoted to making this and related information available to everyone via the internet.

98. **Fueling Global Fishing Fleets**

P. H. Tyedmers, R. Watson, D. Pauly, (2005). *AMBIO: a Journal of the Human Environment* 34, 635-638.

fuel; energy; global fleets

0044-7447, http://www.ecomarres.com/downloads/ambio.pdf

Marine fisheries are the most diverse of the major global food-producing sectors, both in terms of their outputs (species landed1) and the technology used2. One characteristic, however, common to nearly all contemporary fisheries is their dependence on fossil fuels. While numerous analyses have been undertaken to quantify fuel inputs to a wide range of fisheries3,4,5,6,7,8, to date, no attempt has been made to determine the fossil fuel consumption of the world's fishing fleets. Here, we calculate that for 2000, they burned approximately 56.7 billion litres of fuel in the process of landing just over 85 million tonnes of marine fish and invertebrates. Consequently, contemporary fisheries yield approximately 1.77 tonnes of fish per tonne of fuel burned. Moreover, total fuel inputs to the world's fishing fleets account for about 1.4% of total global oil consumption.

99. **Global Trends in World Fisheries: Impacts on Marine Ecosystems and Food Security**

D. Pauly, R. Watson, J. Alder, (2005). *Philosophical Transactions of the Royal Society B: Biological Sciences* 360, 5-12.

global; fisheries; impacts; trends

10.1098/rstb.2004.1574, http://www.ecomarres.com/downloads/Globaltrends.pdf

This contribution, which reviews broad trends in the history of fisheries, argues that sustainability, however defined, rarely if ever occurred as a result of an explicit policy, but as result of our inability to access a major part of exploited stocks. With the development of industrial fishing, and the resulting invasion of the refuges previously provided by distance and depth, our interactions with fisheries resources have come to resemble the wars of extermination that newly arrived hunters conducted 40-50,00 years ago in Australia, and 11-12,000 years ago against large terrestrial mammals. These broad trends are documented here through maps of change in trophic levels and fish sizes, which displays characteristic declines, first in the nearshore waters of industrialized countries of the Northern Hemisphere, then spread offshore and to the Southern Hemisphere. This geographical extension met its natural limit in the late 1980s, when the catches from newly accessed stocks ceased to compensate for the collapsed in areas accessed earlier, hence leading to a gradual decline of global landing. These trends affect developing countries stronger than the developed world, which have been able to meet the shortfall by increasing imports from developing countries. These trends, however, along with the rapid growth of farming of carnivorous fish, which consumes other fish suited for human consumption, has led to serious food security issue. This gives urgency to the implementation of the remedies traditionally proposed to alleviate overfishing (reduction of overcapacity, enforcement of conservative TACs, etc.), and to the implementation of non-conventional approaches, notably the re-establishment of the refuges (a.k.a. marine reserve), which made possible the apparent sustainability of pre-industrial fisheries.

100. **Background and Interpretation of the ‘Marine Trophic Index’as a Measure of Biodiversity**

D. Pauly, R. Watson, (2005). *Philosophical Transactions of the Royal Society B: Biological Sciences* 360, 415-423.

global; trophic level; biodiversity

10.1098/rstb.2004.1597, http://www.ecomarres.com/downloads/BiodiversityTL.pdf

Since the demonstration, in 1998, of the phenomenon now widely known as ?fishing down marine food webs?, and the publication of a critical rejoinder by FAO staff, a number of studies have been conducted in different parts of the world, based on more detailed data than the global FAO fisheries statistics originally used, which established the validity and ubiquity of this phenomenon. In this contribution, we briefly review how, rather than being an artifact of biased data, this phenomenon was in fact largely masked by such data, and is, indeed, more widespread than was initially anticipated. This is here made visible by comparing two global maps of trophic level (TL) changes from the early 1950s to the present. The first presents the 50 year difference of the grand mean TL values originally used to demonstrate the fishing down effect, while the second is based on means above a cutoff TL (here set at 3.25), thus eliminating the highly variable and abundant small pelagic fishes caught throughout the world. Based on this, we suggest that using mean TL as ?Marine Trophic Index? (MTI), as endorsed by the Convention on Biological Diversity always be done with an explicitly stated cutoff TL (i.e., cutMTI), chosen (as is the case with our proposed value of 3.25) such as to emphasize changes in the relative abundance of the more threatened, high-TL fishes. We also point out the need to improve the taxonomic resolution, completeness and accuracy of the national and international fisheries catch data series upon which the cutMTI is to be based.

101. **Mapping Global Fisheries: Sharpening Our Focus**

R. Watson, A. Kitchingman, A. Gelchu, D. Pauly, (2004). *Fish and Fisheries* 5, 168-177.

fisheries landings; fisheries statistics; global fisheries; mapping

1467-2979, http://www.ecomarres.com/downloads/MappingFF.pdf

Mapping global landings is an important prerequisite for examining causal relationships between fishing and ecological change. Landing statistics, typically provided with poor spatial precision, can be disaggregated into a grid system of spatialcells (30 min x 30 min) using a rule-based approach and ancillary data about distributions of fished taxa and fishing access of reporting countries. Presentation of time series catch composition is then possible for many types of marine areas including biogeochemical provinces, large marine ecosystems and exclusive economic zones.

102. **The Future for Fisheries**

D. Pauly, J. Alder, E. Bennett, V. Christensen, P. Tyedmers, R. Watson, (2003). *Science* 302, 1359-1361.

global; biodiversity; catch scenario; energy; fuel

0036-8075, http://www.ecomarres.com/downloads/The%20Future%20of%20Fisheries.pdf

Formal analyses of long- term global marine fisheries prospects have yet to be performed, as fisheries research focuses on local, species-specific management issues. Extrapolation of present trends implies expansion of bottom fisheries into deeper waters, serious impact on biodiversity, and declining global catches, the last possibly aggravated by fuel cost increases. Examination of four scenarios, covering various societal development choices suggests that the negative trends now besetting fisheries can be turned around, and their supporting ecosystems rebuilt, at least partly.

103. **Hundred−Year Decline of North Atlantic Predatory Fishes**

V. Christensen, S. Guenette, J. J. Heymans, C. J. Walters, R. Watson, D. Zeller, D. Pauly, (2003). *Fish and fisheries* 4, 1-24.

Ecopath; saup; biomass decline; ecosystem modelling; Atlantic; predatory fish

1467-2979, http://www.ecomarres.com/downloads/faf103.pdf

We estimate the biomass of high-trophic level fishes in the North Atlantic at a spatial scale of 0.5º latitude by 0.5º longitude based on 23 spatialized ecosystem models, each constructed to represent a given year or short period from 1880 to 1998. We extract over 7 800 data points that describe the abundance of high-trophic level fishes as a function of year, primary production, depth, temperature, latitude, ice cover and catch composition. We then use a multiple linear regression to predict the spatial abundance for all North Atlantic spatial cells for 1900 and for each year from 1950 to 1999. The results indicate that the biomass of high-trophic level fishes has declined by two-thirds during the last 50-year period, and with a factor of nine over the century. Catches of high-trophic level fishes increased from 2.4 to 4.7 million tonnes annually in the late 1960s, and subsequently declined to below 2 million tonnes annually in the late 1990s. The fishing intensity for high-trophic level fishes tripled during the first half of the time period and remained high during the last half of the time period. Comparing the fishing intensity to similar measures from 35 assessments of high-trophic level fish populations from the North Atlantic, we conclude that the trends in the two data series are similar. Our results raise serious concern for the future of the North Atlantic as a diverse, healthy ecosystem; we may soon be left with only low-trophic level species in the sea.

104. **Estimating Illegal and Unreported Catches from Marine Ecosystems: A Basis for Change**

T. J. Pitcher, R. Watson, R. Forrest, H. Þ. Valtýsson, S. Guénette, (2002). *Fish and Fisheries* 3, 317-339.

bycatch; IUU; illegal; catch

1467-2979, http://www.ecomarres.com/downloads/FAF-Pitcheretal2002.pdf

To evaluate the impacts of fishing on marine ecosystems, the total extraction of fish must be known. Putting a figure on total extraction entails the difficult task of estimating, in addition to reported landings, discards, illegal and unmandated catches. Unreported catches cast various types of shadow, which may be tracked and estimated quantitatively. Some shadows of unreported catches are reviewed, for example, an innovative, well-funded NGO publicizes illegal catch inthe Southern Ocean. For various reasons, official figures often have the implicit but unacceptable assumption that such categories are null.We present an estimation procedure based on adjustment factors taken from observer reports, correspondents and published information that track changes in a regulatory regime, and hence reflect incentives and disincentives to misreport. Monte Carlo simulations address uncertainty using multiple sources of information to provide upper and lower estimates. Once in place, this method provides preliminary estimates that may be refined without disruption. The method is demonstrated for fisheries in Iceland and Morocco. We use a ?by-species? approach for Icelandic cod and haddock, while the Moroccan catch is divided into demersal and pelagic categories. Results suggest that Icelandic cod catches may have been underestimated by between 1 and 14% at different times, and haddock by between 1 and 28%. Underestimation of Moroccan catches appears to have been as much as by 50%. These case studies show that it is possible to obtain estimates of misreporting, even when direct data are lacking. Our method encourages transparency because sources of information are presented so that uncertain values are easily identifed, offering a basis for comment, collaboration and refinement in estimating illegal and unreported fishing.

105. **Towards Sustainability in World Fisheries**

D. Pauly, V. Christensen, S. Guénette, T. J. Pitcher, U. R. Sumaila, C. J. Walters, R. Watson, D. Zeller, (2002). *Nature* 418, 689-695.

sustainability; fisheries; global

10.1038/nature01017, http://www.ecomarres.com/downloads/Pauly-et-al-Nature2002.pdf

Fisheries have rarely been 'sustainable'. Rather, fishing has induced serial depletions, long masked by improved technology, geographic expansion and exploitation of previously spurned species lower in the food web. With global catches declining since the late 1980s, continuation of present trends will lead to supply shortfall, for which aquaculture cannot be expected to compensate, and may well exacerbate. Reducing fishing capacity to appropriate levels will require strong reductions of subsidies. Zoning the oceans into unfished marine reserves and areas with limited levels of fishing effort would allow sustainable fisheries, based on resources embedded in functional, diverse ecosystems.

106. **Systematic Distortions in World Fisheries Catch Trends**

R. Watson, D. Pauly, (2001). *Nature* 414, 534-536.

landings; saup; China; global; bias

0028-0836, http://www.ecomarres.com/downloads/Nature.pdf

Over 75% of the world marine fisheries catch (over 80 million tonnes per year) is sold on international markets, in contrast to other food commodities (such as rice). At present, only one institution, the Food and Agriculture Organization of the United Nations (FAO) maintains global fisheries statistics. As an intergovernmental organization, however, FAO must generally rely on the statistics provided by member countries, even if it is doubtful that these correspond to reality. Here we show that misreporting by countries with large fisheries, combined with the large and widely fluctuating catch of species such as the Peruvian anchoveta, can cause globally spurious trends. Such trends influence unwise investment decisions by firms in the fishing sector and by banks, and prevent the effective management of international fisheries.

107. **A Dynamic Mass-Balance Model for Marine Protected Areas**

R. Watson, J. Alder, C. J. Walters, (2000.). *Fish and Fisheries* 1, 94-98.

marine protected areas; ecological models; Ecosim; Ecopath; marine reserves; MPA

1467-2979, http://www.ecomarres.com/downloads/reprint_mpa.pdf

A modified EcoSim model was used to investigate the impact of establishing marine protected areas (MPAs) in ecosystems defined by existing EcoPath models. The impacts of MPAs of various sizes was stimulated, and changes in biomass and catch over a range of years observed. The response of biomass and catch to MPA size depended on the time period examined. For some ecosystem groups, the initial was negative, but for all groups there were increases after 10 years. The greater the biomass exchange across the MPA boundary, the larger the MPA required to increase biomass levels. Within the range of exchange rates simulated, the maximum increase in catch and overall biomass levels were reached when 20% of the system was protected.

108. **Marine Reserves and the Restoration of Fisheries and Marine Ecosystems in the South China Sea**

T. J. Pitcher, R. Watson, N. Haggan, S. Guénette, R. Kennish, U. R. Sumaila, D. Cook, K. Wilson, A. Leung, (2000). *Bulletin of Marine Science* 66, 543-566.

MPA; China; Hong Kong; ecosystem

0007-4977, http://www.ecomarres.com/downloads/marinereserves.pdf

The South China Sea has been devastated by human fishing. This paper reports an initiative to restore Hong Kong's marine ecosystems and fisheries through the deployment of artificial reefs (ARs) within marine protected areas (MPAs). Current catch and biomass data by species and fishery sector were available. Quasi-spatial ecosystem simulations, using a modified ECOSIM method, have been employed to forecast benefits from a successful MPA/ AR system. Results indicate that, despite increasing fishing power in the Hong Kong fleet, a 10-20% MPA/AR system could provide significant benefits within 10 yrs, and shifts to low-value pelagic fish could be reversed. Approximate scores, expressing how species benefit from protectedARs, suggest that results are not biased by changes in species composition. The design of MPA/ ARs balances island biogeographic theory with the needs of monitoring and compliance: minimizing perimeter losses and establishing colonizing corridors are trade-offs with statistical replication and monitoring, whereas sacrifice of some ARs to fishing encourages compliance and learning. In Hong Kong, workshops with fishing communities encouraged support. Bioeconomic analysis shows an MPA/ AR system increasing fishery value, but noncompliance rapidly erodes benefits. The benefits of this approach are assessed together with problems and difficulties that have arisen.

109. **Uncertainty and Risk Associated with Optimised Fishing Patterns in a Tropical Penaeid Fishery**

R. A. Watson, N. R. Sumner, (1999). *Environment international* 25, 735-744.

shrimp; prawn; model; optimisation; fisheries

0160-4120, http://www.ecomarres.com/downloads/WatsonSumner.pdf

Simulation was used to improve the management of prawn fisheries by indicating patterns of fishing effort which favour the harvest of more highly valued, larger animals. Attempts to use conventional local optimisation methods to find the optimum pattern ofweekly fishing efforts were ineffective. Simulating annealing, a global optimisation method, was used effectively to find fishing effort patterns which maximised catch values. Sensitivity of the maximum catch value to the parameters used to model fishing and biological behaviour was also investigated. The optimum catch value was not sensitive to variations in trawl net selectivity or catchability parameters, although the optimum fishing season to obtain these maxima altered. In contrast, changes to biological parameters had a notable effect on the maximum catch value, despite compensatory changes to the optimum weekly pattern of fishing effort. The risk associated with achieving management goals using a range of fishing strategies was also assessed when recruitment timing and growth rates were modelled as partly stochastic. With uncertainty in recruitment timing, it was found that the optimum fishing pattern did not change. Uncertainty in growth rates made fishing earlier the best strategy , and increased harvest values in 43% of simulations.

110. **Performance of Transect and Point Count Underwater Visual Census Methods.**

R. A. Watson, T. J. Quinn II, (1997). *Ecological Modelling* 104, 103-112.

visual census; transect; dive; census; model; simulation; coral reef

, http://www.ecomarres.com/downloads/uvc2.pdf

A simulation approach was used to study bias and variability of density estimates of fish using the transect and point count underwater visual census methods. Three experiments were conducted to examine the effects of fish density, sampling effort, and the speed of fish in relation to the observer. Fish density and sampling effort did not significantly bias estimates of fish density using either census method, and variation was a function of the area sampled with both methods. The speed at which fish approached the diver caused appreciable bias with the transect method but not with the point count method, because of underlying assumptions about how the two methods were implemented. Performance of methods was quantified with the root mean squared error RMSE (combined measure of bias and variability) and was dependent on the ratio of sampling times per dive for each method. From assumed sampling times for the point count and transect methods, the point count method performed better than the transect method, but different results could be obtained under different sampling protocols. Nevertheless, the simulation approach offers an efficient means to evaluate sampling methods in conjunction with actual field experiments.

111. **Identifying Tropical Penaeid Recruitment Patterns**

R. Watson, C. T. Turnbull, K. J. Derbyshire, (1996). *Marine and freshwater research* 47, 77-85.

shrimp; recruitment; model; Australia

1448-6059, http://www.ecomarres.com/downloads/PrawnRecruitment.pdf

Knowledge of recruitment patterns is a requisite for modern fisheries management. These patterns can range in complexity from a single pulse of identically sized and aged prawns, which is often assumed in fisheries models, to continuous recruitment by prawns of several ages. Existing techniques used to identify recruitment patterns range from the ad hoc use of size limits to more complex methods that examine changes in length-frequency modes through time. A model that allowed variable growth of individuals was used to simulate monthly length-frequency fisheries data from a range of recruitment patterns of varying complexity. The effectiveness of a range of methods to identify these underlying recruitment patterns was examined. Length-frequency survey data from tropical penaeid fisheries for Penaeus esculentus, the brown tiger prawn, in two locations off north-eastern Australia (Torres Strait and Turtle Island Group) were also subjected to these methods. Methods that employed simple truncation by length successfully identified simple recruitment patterns but were not effective for multi-age recruitment patterns. Only the length-cohort and age-cohort methods could identify the presence of older recruits in multi-age patterns. All methods were sensitive to estimates of growth parameters, particularly the cohort-based methods. Results suggest that P. esculentus from the two fisheries examined had different recruitment patterns requiring different management approaches.

112. **Evaluating Closed Season Options with Simulation for a Tropical Shrimp Fishery**

R. A. Watson, V. R. Restrepo, (1995). *ICES Marine Science Symposia* 199, 391-398.

shrimp; model; optimisation; closures; prawn

0906-060X, http://www.ecomarres.com/downloads/evalclosure.pdf

We used simulation modelling to find seasonal closures which maximized either yield per recruit (Y/R) or relative value per recruit (V/R) for several tropical shrimp fisheries. Each case examined represented a choice of (1) a single versus a multicohort population, (2) the reduction of annual fishing effort levels through closures versus its redistribution to the fishing season, and (3) a range of fishing mortality levels. Under most conditions, seasonal closures which maximized Y/R also maximized V/R, though simulated gains in the latter were smaller. Timing of seasonal closures was more critical for fisheries of single-cohort populations than multicohort populations. Multicohort-based fisheries required shorter seasonal closures to maximize V/R than did those based on single-cohort populations. Assumptions about the disposition of fishing effort normally expended during the period of a seasonal closure greatly affected the best closure choice. Predicted best closures were of a longer duration when annual fishing effort was simply redistributed rather than reduced by closures. Greatest improvements in Y/R (30 to 40%) were obtained for fisheries based on singlecohort populations when closure effort was redistributed. Predicted increases in Y/R for multicohort-based fisheries never exceeded 7%. The duration of best closures increased with increasing values of fishing mortality when the annual fishing effort was reduced by closures. This trend was reversed when annual fishing effort was conserved. As fishing mortality increased, potential gains in Y/R or V/R improved at the cost of equilibrium egg production.

113. **Bias Introduced by the Non-Random Movement of Fish in Visual Transect Surveys**

R. Watson, G. M. Carlos, M. A. Samoilys, (1995). *Ecological Modelling* 77, 205-214.

transect; diver; survey; model; simulation; coral reef

0304-3800, http://www.ecomarres.com/downloads/Bias.pdf

Non-random movement has been observed in a number of reef fish species but its effect on visual counts has not been previously examined. A simulation program Reefex was used to examine the relationship between speed and approach angle of fish, and the degree of bias introduced in estimates of fish numbers from visual transects. Fish approaching at right-angles to the direction of the direction of the transect did not introduce a bias regardless of their speed. Fish approachIng against the diver introduced a positive bias which increased linearly with fish speed. Fish moving in direction of the diver created a negative bias, fish counts decreased linearly until fish speed matched that of diver. This minimum value reflected the immediately visible portion of the entire transect that could be surveyed instantaneously by the diver when the survey began. Changes in the effective area surveyed determine bias. An equation is presented which relates bias to fish speed, angle of approach, diver speed, transect length and visibility.

114. **Closed Seasons and Tropical Penaeid Fisheries: A Simulation Including Fleet Dynamics and Uncertainty**

R. A. Watson, D. J. Die, V. R. Restrepo, (1993). *North American Journal of Fisheries Management* 13, 326-336.

model; shrimp; simulation; optimisation; fleet; model; prawn; Australia; Torres Strait

0275-5947, http://www.ecomarres.com/downloads/closures.pdf

Seasonal fishery closures are commonly used in fisheries management for various purposes, including limitation of effort, protection of spawners, and maximization of the yield or value that can be obtained from a cohort. The effectiveness of a proposed closure can be evaluated through yield-per-recruit analysis, which can be carried out analytically for some simple situations. For other fisheries, such as the penaeid shrimp fishery of Torres Strait, Australia, investigated here, the analyses are more complex because recruitment occurs in pulses throughout the year and the intensity of fishing is itself unevenly distributed in time, being patterned after these recruitment pulses. Furthermore, the imposition of closures of different durations has been documented to alter the pattern and intensity of fishing after the fishery reopens. In this study, a simulation approach is used to identify the timing and duration of closures that are likely to increase the yield or the value per recruit of the fishery. The simulation allows for changes in the distribution and magnitude of effort directly caused by the closures. All input parameters are assumed to be known precisely, except those controlling fishing and natural mortality, which are drawn from empirically derived ranges. The simulation results indicate that a 6-month closure starting in December or January could increase the value of the fishery by 5-10%, compared with a fishery with the same fishing pattern and no closure.

115. **Simulation Estimates of Annual Yield and Landed Value for Commercial Penaeid Prawns from a Tropical Seagrass Habitat, Northern Queensland, Australia**

R. A. Watson, R. G. Coles, W. J. L. Long, (1993). *Marine and Freshwater Research* 44, 211-219.

shrimp; value; yield; seagrass; Australia; model; simulation; prawn

1448-6059, http://www.ecomarres.com/downloads/MF9930211.pdf

Concern over the loss of seagrass habitat has prompted examination of the value of the production of commercial prawns from such habitat. Cairns Harbour in tropical northern Queensland has 876 ha of mixed seagrasses, dominated by Zostera capricorni and Halodule pinijolia, that support a multispecies commercial penaeid prawn fishery offshore. Densities of juvenile commercial prawns estimated from seagrass surveys were used to project estimates of annual yield and landed value, using a deterministic simulation model employing lunar-period time steps. Estimates of the potential total annual yield from Cairns Harbour seagrasses for the three major commercial prawn species (Penaeus esculentus, P. semisulcatus and Metapenaeus endeavouri) were 178 t (range 81-316 t) year-1 with a landed value of .2 million (range $0.6 million to $2.2 million) year-l.

116. **Migration and Growth of Two Tropical Penaeid Shrimps within Torres Strait, Northern Australia**

R. Watson, C. T. Turnbull, (1993). *Fisheries Research* 17, 353-368.

prawn; shrimp; Torres Strait; Australia; migration; growth; tiger prawn; endeavour prawn

10.1016/0165-7836(93)90135-T, http://www.ecomarres.com/downloads/prawngrow.pdf

In total 9259 brown tiger shrimp, Penaeus esculentus and 4705 endeavour shrimp, Metapenaeus endeavouri, were tagged and relaeased in Torres Strait. Within 4 months 8% of tagged P. esculentus and 2% of tagged M. endeavouri were recaptured by commercial shrimp trawlers. Return rates were three to six times greater for shrimp released within the commercial fishery to the east of Warrior Reefs, than those released to the west. Shrimp released to the west of the Warrior Reefs, which is permanently closed to fishing, averaged 7–10 weeks at liberty and travelled an average of 55 km before recapture, compared with a 3–4 week, 5-km journey for those released in the east. We established that the growth parameter K should be estimated separately for males and females of the two species. In contrast to P. esculentus, a common estimate of the growth parameter L_∞ was indicated for both sexes of M. endeavouri. Although female M. endeavouri generally did not grow as large as female P. esculentus the males of the two species grew to a similar size. Net migration speeds, distance and direction were estimated. After correction for the spatial-temporal distribution of fishing effort there was still evidence of an eastward and southward movement of all tagged shrimp indicating that P. esculentus and M. endeavouri migrated from the unfished West into the East and contributed to commercial catches in the fishery.

117. **Distribution of Seagrasses, and Their Fish and Penaeid Prawn Communities, in Cairns Harbour, a Tropical Estuary, Northern Queensland, Australia**

R. G. Coles, W. J. L. Long, R. A. Watson, K. Derbyshire, (1993). *Marine and Freshwater Research* 44, 193-210.

seagrass; shrimp; habitat prediction; Australia

1448-6059, http://www.ecomarres.com/downloads/MF9930193.pdf

From aerial photography (July 1987) and diving surveys (February 1988), 876 ha of seagrasses (eight species) were mapped in Cairns Harbour, tropical north-eastern Queensland. Zosteru cupricorni was the most common seagrass species and had the greatest biomass at 79 9 m-2 dry weight of stems and leaves and 180 9 m-2 dry weight of roots and rhizomes. The maximum shoot density found was 4798 shoots m-2 of Hulodule pinijoliu, the second most common species. Seagrasses were found only between 0.5 and 5.0 m below mean sea level. Zosteru cupricorni was found at the shallowest depths, Hulodule pinifoliu at the deepest depths. Twenty species of penaeid prawns, nine of which are marketed commercially, were sampled from the seagrass beds. Abundances of prawns of commercial species were significantly greater on seagrass-covered substrata than on nonvegetated substrata. Overall, 5614 mostly small or juvenile fish, representing 134 taxa, were sampled from seagrasses in Cairns Harbour. The most numerous fish species were a goby, Yongeichthys criniger, and a pony fish, Leiognuthus splendens. Only 15 species were highly valued as recreational fish, and only 11 species were highly valued as commercial fish. Of the fish species, five (4%) were highly valued species of both groups. The density of fish on the seagrass beds was estimated to be 8809 fish ha-1.

118. **Sledges for Daytime Sampling of Juvenile Penaeid Shrimp**

C. T. Turnbull, R. A. Watson, (1992). *Fisheries research* 14, 31-40.

shrimp; prawn; sampling; juvenille; seagrass

0165-7836, http://www.ecomarres.com/downloads/sledges.pdf

Daytime catches ofjuvenile penaeid shrimp from two modified sledges (providing stimulation by water-jet or electric current) were compared with catches from a conventional sledge (or beam trawl) used at night. The results indicate that the daytime use of a water-jet sledge is a suitable alternative when night-time sampling is precluded. Mean catch rate of the Brown tiger prawn (Penaeus esculentus) in the daytime water-jet sledges was not significantly different from the night-time conventional sledges. but catches in the daytime electric trawls were significantly less. In contrast, the catches of the Endeavour shrimp (Metapenaeus endeavouri) and the Greentail shrimp (Metapenaeus bennettae), in both the daytime water-jet and daytime electric sledges, were significantly lower (approximately one-quarter) than in the night-time trawls. There was no significant difference between the length frequency distributions of P. esculentus, M. endeavouri or M. bennettae caught in the conventional night-time and in the daytime water-jet sledges.

119. **Dissipation of Spatial Closure Benefits as a Result of Non-Compliance**

D. J. Die, R. A. Watson, (1992). *Mathematics and computers in simulation* 33, 451-456.

value; compliance; closure; model; simulation; Australia

0378-4754, http://www.ecomarres.com/downloads/Dissipation.pdf

Spatial closures are imposed by resource managers to prevent the operation of fishing fleets in certain areas of a stock's distribution. In Queensland, east coast trawl closures are usually located in shallow waters to prevent fishing of prawns before they reach an optimum marketable size and migrate offshore. The success of such fishery controls should be measured by careful analysis of the benefits to fishery production, and the costs and practicality of enforcing the regulation. The potential of simulation models to investigate optimising fishery production by adjusting the starting date, length and extent of a fishing closure has been established in the Torres Straits tiger prawn fishery. It was predicted that by modifying the length and starting dates of seasonal closures that gains of up to 15% in yield-per-recruit and value-per-recruit could be achieved. By comparison, the best gains predicted by adjusting the boundaries of permanent spatial closures were less than 10% of value-per-recruit and negligible for yield-per-recruit. Enforcing fisheries regulations is expensive and especially difficult in the case of spatial closures. Most fishers are aware of this difficulty and some fish in closed areas because of the competitive advantage and the short-term benefits this practice provides. Therefore, it is important to evaluate the level of non-compliance which would dissipate the benefits gained from any closure regulations. In this paper the effect of cheating is evaluated by value-per-recruit and egg-per recruit analysis.

120. **A Per-Recruit Simulation Model for Evaluating Spatial Closures in an Australian Penaeid Fishery**

D. J. Die, R. A. Watson, (1992). *Aquatic Living Resources* 5, 145-153.

simulation; shrimp; prawn; Australia; closure; model

1765-2952, http://www.ecomarres.com/downloads/PerRecruit.pdf

Spatial closures are commonly used by Australian fisheries managers to alter fishing patterns. To evaluate different fishing closures, however, fishery scientists have to understand and model the spatiotemporal interactions between fish stocks and fishing fleets. We develop a deterministic, stationary, per-recuit, age-structured simulation model to assess different spatial closure strategies, and use date from the Torres Strait tiger prawn fishery, Penaeus esculentus, as a working example. Our results show that selection of an optimum spatial closure largely depends on the relative importance given to changes of the different utility functions evaluated (yield, value, egg production). We show that, on average, with a spatial closure yield-per-recruit would decrease, but also show that value-per-recruit may increase 10% with the appropriate closure. Our results suggest that egg-per-recruit would always increase in the presence of a closure. By incorporating parameter uncertainty within the simulation model we predict the uncertainty associated with alternative closure strategies, and thus provide valuable information for the decision-making process.

121. **An Approach to Modelling Crustacea in Egg-Bearing Fractions as a Function of Size and Season**

V. R. Restrepo, R. A. Watson, (1991). *Canadian Journal of Fisheries and Aquatic Sciences* 48, 1431-1436.

shrimp; reproduction; model; prawn; crustacean

, http://www.ecomarres.com/downloads/crust.pdf

We present an approach to the analysis of crustacean egg production ogives with emphasis on detecting seasonal trends. The relationship between the proportion of gravid females (by size) and season is a prerequisite to the estimation of egg production potentials of populations. The basic method consists of relating, for each sample, the proportion of berried females with their size through a three-parameter logistic function where the asymptote may be less than 1. We then provide guidance for detecting seasonal trends in the estimates of the parameters for the individual samples. This is accomplished by restricting the basic model such that some parameters are considered to be either fixed for all samples or as simple functions of time or environmental variables such as temperature. Parameter estimates are obtained via maximum likelihood methods, and comparisons between alternative models are presented graphically and using likelihood ratio tests. We illustrate the approach and its application with data for a tropical shrimp, Penaeus esculentus, from northern Australia. Nous presentons une approche pour I`analyse des enveloppes d`oeufs de crustaces qui insiste sur la detection des tendances saisonnieres. Le rapport entre la proportion de femelles gravides (par taille) et la saison est un prerequis pour I'evaluation du potentiel de production d'oeufs des populations. La methode de base est basee sur I'etablissement de rapports, pour chaque echantillon, entre la proportion des femelles porteuses d'oeufs avec leur taille grace a une fonction logistique a trois parametres dont I'asymptote peut etre inferieure a un. Nous don nons ensuite des conseils permettant de deceler les tendances saisonnieres dans les evaluations des parametres d'echantillons individuels. On y arrive en restreignant le modele de base de facon a ce que certains parametres soient consideres comme etant soit fixes pour tous les echantillons, ou soit de simples fonctions du temps de variables environnementales comme la temperature. Des evaluations de parametres sont obtenues par la methode de la vraisemblance maximum et des comparaisons entre plusieurs modeles possibles sont presentees graphiquement et utilisent des tests de rapports de ressemblance. Nous illustrons cette approche et son application avec des donnees obtenues pour une crevette tropicale, Penaeus esculentus, provenant du nord de l`Australie.

122. **Spatial and Seasonal Variation in Demersal Trawl Fauna Associated with a Prawn Fishery on the Central Great Barrier Reef, Australia**

R. Watson, M. L. C. Dredge, D. G. Mayer, (1990). *Marine and Freshwater Research* 41, 65-77.

bycatch; trawl; shrimp; Australia; coral reef; GBR

1448-6059, http://www.ecomarres.com/downloads/MF9900065.pdf

Regular monthly sampling at eight trawl sites in Great Barrier Reef waters identified variations in both species composition and the relative abundance of the more common species over a 2-year period. Faunal composition was affected more by the location of sample sites than by the time when samples were taken. Ordination analysis differentiated a 'nearshore' group of sites from a 'midshelf' and an 'inter-reef' group. The composition of 'inter-reef' fauna remained strikingly uniform below the 40 m depth contour regardless of proximity to coral reef formations. Classification of the samples also revealed weakly separated 'wet' and 'dry' season temporal groupings, with the former characterized by higher abundances of several 'nearshore' species.

123. **Velvet Prawns (Metapenaeopsis Spp) of Torres Strait, Queensland, Australia**

R. A. Watson, J. Keating, (1989). *Asian Fish. Sci* 3, 45-56.

shrimp; prawn; Torres Strait; Australia; velvet prawn; biology; recruitment; reproduction

, http://www.ecomarres.com/downloads/velvet.pdf

The velvet shrimps, Metapenaeopsis rosea (Racek and Dall 1965) and M. palmensis (HasweIl1879), form a large part of penaeid shrimp catches from Torres Strait, Queensland, Australia, and are caught from 5 to 30 mm carapace length. Recruitment to the fishery occurs annually in January to March and abundance is greatest during May to October. Females are first found mature at 12 mm carapace length and spawning occurs year-round with peaks in April, July and October. Males begin to mature at 5 mm carapace length and all have joined petasmas by 9 mm carapace length. M. rosea males are heavier than their female counterparts at any given carapace length and no difference was found between male and female M. palmensis. Male and female M. rosea were heavier than those of M. palmensis at the same length. Until recently catches of these species were discarded but increasingly those of larger sizes are retained and marketed.

124. **Temporal and Spatial Zonation of the Demersal Trawl Fauna of the Central Great Barrier Reef**

R. Watson, G. Goeden, (1989). *Memoirs of the Queensland Museum* 27, 611-620.

coral reef; GBR; MPA; Australia; bycatch

0079-8835, http://www.ecomarres.com/downloads/reefmus.pdf

Management needs for zonation of the central Great Barrier Reef Marine Park by user activity prompted a study of the demersal trawl fauna from a range of sites. Cluster analysis revealed three distinct site assemblages: 'coastal' , 'inshore' , and 'inter-reef' , characterized by the conspicuous abundance of some species and the absence of other species. The location of these assemblages was related to water depth, sediment particle size composition and distance offshore but could not be explained by the distribution of fishing effort. Some sites, intermediate in location between these assemblages, were assigned to a 'transitional' assemblage in which sites changed affiliation temporally.

125. **Growth, Mortality, Parasitism, and Potential Yields of Two Priacanthus Species in the South China Sea.**

R. J. G. Lester, R. A. Watson, (1985). *J. Fish Biol.* 27, 307-318.

trawl; Hong Kong; China; growth; mortality; parasitology; yield; bigeye

, http://www.ecomarres.com/downloads/Priacanth.pdf

In the northern part of the South China Sea the 'big-eye' Priacanthus tayenus, spawned once a year in June, had von Bertalanffy growth parameters of k = 0.8 and Linf = 30 cm, and a mean total annual instantaneous mortality of Z = 2.0, calculated from adjusted catch curves and a mean length equation. The natural mortality rate M = 1.4, fishing mortality rate F = 0.6, and the exploitation rate (E) was 0.27. The maximum potential yield, calculated using Marten's method, was 0.06 kg/recruit when F= 5.4. The fish were heavily parasitised by the protozoan Pleistophora priacanthicola. A second big-eye, P. macracanthus, spawned twice a year in May-June and September, had growth parameters of k=0.7 and Linf = 32, and population parameters of Z =2.0, F=0.7, and E=0.34. The maximum potential yield was 0.13 kg/recruit when F= 5.8. A marked reduction in fishing mortality occurred for both species between 1965 and 1966, coinciding with the onset of the Chinese Cultural Revolution. Our estimates of maximum potential yield correspond to fishing mortalities eight times estimated levels, though such heavy exploitation could risk recruitment failure.

126. **The Life Cycle and Morphology of Tetracerasta Blepta, Gen. Nov. Sp. Nov. And Stegodexamene Callista, Sp. Nov. (Trematoda: Lepocreadiidae) from the Long Finned Eel, Anguilla Reinhardtii Steindachner.**

R. A. Watson, (1984). *Aust. J. Zool.* 32, 177-204.

parasitology; Australia; trematode; lifecycle

, http://www.ecomarres.com/downloads/Lifecycle.pdf

Two new lepocreadiid digeneans, Tetracerasta blepta, gen. sp. nov., and Stegodexamene callista, sp. nov., are described from the intestine of the long-finned freshwater eel, Anguilla reinhardtii, in the Brisbane River, Queensland, and from the Australian bass, Macquaria novemaculeata, in the Richmond River in New South Wales. Their life cycles have been elucidated and completed in the laboratory, by means of uninfected hosts. Both lepocreadiid species use the prosobranch gastropod, Posticobia brazieri, as their first intermediate host. Cercariae of T. blepta penetrate and encyst in the pharyngeal muscle, external muscle, and viscera of fishes in the genera Gobiomorphus and Hypseleotris, and in several species of tree frog tadpoles. The cercariae of S. callista are often eaten or accidentally inhaled by several small fishes, including Retropinna, Craterocephalus, Pseudomugil and Ambassis, and encyst in the pharyngeal muscle and viscera. All developmental stages are described and illustrated.

127. **Metazoan Parasites of Pike, Esox Lucius Linnaeus, from Southern Indian Lake, Manitoba, Canada.**

R. A. Watson, T. A. Dick, (1980). *J. Fish Biol.* 17, 225-261. .

pike; freshwater; impacts; parasitology; Canada

, http://www.ecomarres.com/downloads/Metazoan2.pdf

Metazoan parasites of pike Esox lucius from Southern Indian Lake, Manitoba were studied to reveal species composition, differences with host age, sex, and location and season of capture. Pike hosted 18 species of metazoan parasites, two of which, Tetraonchu, monenteron and Proteocephalus pingui.5, made up over 84% of metazoan parasite numbers. Some parasite species exhibited defInite patterns of abundance with host age and season which resulted from changes in host diet and behaviour. No differences in parasite abundance existed between the host sexes. Ranking of parasite abundances was significantly different between two sampling sites only 2 km apart as a result of intermediate host distribution. Impoundment could greatly change pike parasite levels. An initial decrease in parasite numbers could be followed by a rapid increase.

128. **The Metazoan Parasites of Whitefish Coregonus Clupeaformis and Cisco C. Artedii from Southern Indian Lake, Manitoba.**

R. A. Watson, T. A. Dick, (1979). *J. Fish Biol.* 15, 579-587.

parasitology; freshwater; impacts; Canada

, http://www.ecomarres.com/downloads/Metazoan.pdf

Metazoan parasites of whitefish Coregonus clupeaformis and cisco C. artedii from Southern Indian Lake, Manitoba were studied to reveal: species composition, differences with host age, sex, and location and season of capture. Whitefish hosted 19 species, 18 of which were also in cisco with generally lower intensity levels. Parasites exhibited definite patterns of abundance with host age and season, the primary causes being dietary and behavioural. No differences in parasite abundance existed between host sexes. Ranking of cisco parasites was significantly different between two sampling sites while whitefish parasites did not differ. Whitefish and cisco from sites 40 miles (64 km) apart had significantly different abundances of Tetracoty/e intermedia but not Triaenophorus crassus. An increase in the abundance of copepod-vectored cestodes with a concomitant decrease in abundance of amphipodvectored parasites is predicted after flooding and diversion.

129. **The Whitefish Pike Parasite Triaenophorus Crassus**

T. A. Dick, R. A. Watson, (1977). *Manitoba Nat.* 17, 26-31.

parasitology; freshwater; tapeworm; Canada

, http://www.ecomarres.com/downloads/tapeworm.pdf

"Parasites"! This word conjures up two unpleasant images in the thoughts of man; the first, individuals who benefit at the expense of other members of society without themselves making a contribution. The second image is that of death caused by parasites such as malaria, of malnutrition caused by hookworms, and of damage to the productivity of crops and livestock. It is not surprising then that any host animal which has parasites is immediately condemned unfit to eat. But this is not always the case and certainly not so for the tapeworm Triaenophorus crassus in whitefish. The presence of T. crassus larvae (an immature stage) coiled in a cyst in the flesh of whitefish or ciscoes is objectionabte to the consumer housewife, who quickly reaches for unparasitized marine fishes. Wormy fish are condemned and the commercial fishermen receive little reward for their efforts to harvest these products of our great western lakes.

130. **Where Fisheries Have Been, and Why They Are Going.**

P. D., R. Watson, D. Zeller, in *Sea the Truth: Essays on Overfishing, Pollution and Climate Change.*, K. Soeters, Ed. (Nicolaas G. Pierson Foundation, Amsterdam, The Netherlands., 2012), pp. 15-26.

131. **How Much Fish Is Being Extracted from the Oceans and What Is It Worth.**

R. Watson, R. Sumaila, D. Zeller, in *Ecosystem Approaches to Fisheries: A Global Perspective.*, V. Christensen, J. Maclean, Eds. (Cambridge University Press, 2011), pp. 350pp.

132. **Global Fisheries Economic Analysis.**

U. R. Sumaila, A. J. Dyck, A. M. Cisneros-Montemayor, R. Watson, in *Ecosystem Approaches to Fisheries: A Global Perspective.*, V. Christensen, J. Maclean, Eds. (Cambridge University Press, 2011), pp. 350pp.

133. **Database-Driven Models of the World's Large Marine Ecosystems**

V. Christensen, C. J. Walters, R. Ahrens, J. Alder, J. Buszowski, L. B. Christensen, W. W. L. Cheung, J. Dunne, R. Froese, V. Karpouzi, K. Kaschner, K. Kearney, S. Lai, V. Lam, M. L. D. Palomares, A. Peters-Mason, C. Piroddi, J. L. Sarmiento, J. Steenbeek, R. Sumaila, R. Watson, D. Zeller, D. Pauly, in *Sustainable Development of the World's Large Marine Ecosystem During Climate Change: A Commemorative Volume to Advance Sustainable Development on the Occasion of the Presentation of the 2010 Göteborg Award,* K. Sherman, S. Adams, Eds. (IUCN, Gland, Switzerland, 2010.), pp. 74-103.

134. **Spatial Dynamics of Marine Fisheries**

D. Pauly, R. Watson, in *The Princeton Guide to Ecology*. (2009), pp. 501-509.

135. **Catches from World Seamount Fisheries**

R. Watson, A. Kitchingman, W. W. Cheung, in *Seamounts: Ecology, Fisheries & Conservation,* T. P. Pitcher, T. Morato, P. J. B. Hart, M. R. Clark, N. Haggan, R. S. Santos, Eds. (Blackwell, Oxford, UK, 2008), pp. 400-412.

136. **Fisheries in Large Marine Ecosystems: Descriptions and Diagnoses.**

D. Pauly, J. Alder, S. Booth, W. W. L. Cheung, V. Christensen, C. Close, U. R. Sumaila, W. Swartz, A. Tavakolie, R. Watson, L. Wood, D. Zeller, in *The Unep Large Marine Ecosystem Report: A Perspective on Changing Conditions in Lmes of the World's Regional Seas,* K. Sherman, G. Kempel, Eds. (UNEP, Nairobi, 2008), vol. UNEP Regional Seas Reports and Studies, pp. 23-40.

137. **Counting the Last Fish**

D. Pauly, R. Watson, in *Oceans: A Scientific American Reader,* S. American, Ed. (University of Chicago Press, 2007), pp. 127-134.

138. **Globalization: Effects on Fisheries Resources**

J. Alder, R. Watson, in *Fisheries Globalization: Fair Trade or Piracy,* W. W. Taylor, M. G. Schechter, L. G. Wolfson, Eds. (Cambridge University Press, 2007), pp. 47-74.

139. **Mapping Fisheries onto Marine Ecosystems for Regional, Oceanic and Global Integrations**

R. Watson, D. Pauly, V. Christensen, R. Froese, A. Longhurst, T. Platt, S. Sathyendranath, K. Sherman, J. O'Reilly, P. Celone, in *Large Marine Ecosystems of the World: Trends in Exploitation, Protection, and Research.,* G. Hempel, K. Sherman, Eds. (Elsevier, Amsterdam, 2003), pp. 365-396.

140. **Global Overfishing**

R. Watson, D. Pauly, in *National Geographic Atlas of the Ocean: The Deep Frontier,* E. Earle, Ed. (National Geographic, Washington, D.C., U.S.A, 2001), pp. 163.

141. **Mapping Global Fisheries' Indicators and Potential Conflicts**

R. Watson, K. Kaschner, (2004). 20p.

global, fisheries, marine mammal, diet, overlap

paper published in proceedings of the *National Symposium on Ecosystem Research and the Management of Fisheries of Fish and Fisheries*, Adelaide, South Australia, 19-24 September, 2004

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142. **Spatial Allocation of Global Fisheries Landings Using Rule-Based Procedures**

R. Watson, (2004). 381-390.

mapping, global, landings, saup

http://www.ecomarres.com/downloads/Spatialallocation.pdf

paper published in proceedings of the *Second International Symposium on GIS/Spatial Analysis in Fishery and Aquatic Sciences*, University of Sussex, Brighton, U.K., 3-6 September, 2002

Examination of the effects of fishing on marine ecosystems requires historical catch data on appropriate spatial scales. Most commercial fishing data are currently only available in the form of landings data that do not delineate the marine area from which the catch was extracted. Even when statistics are available by defined spatial areas rather than by port landings, such as the statistical areas used by the Food and Agriculture Organization (FAO) of the United Nations, these reporting areas are often much larger in extent than the areas defined as ecosystems by most current ecological models and are difficult to use without modification. A rule-based spatial allocation procedure was employed using a Microsoft Visual Basic application called ?SimMap? that has the ability to create and decompose ArcView shapefiles. An ESRI plug-in (Map Objects Lite) was used to provide the ability to show shapefiles created dynamically as a result of the catch allocation process. By creating Access databases describing the distribution of some 1 500 commercial fisheries taxa, as well as the plethora of fishing access arrangements nations have with other nations, we were able to create procedures for spatially allocating broader fisheries catch statistics into a global system of 30-minute latitude by 30-minute longitude spatial cells. This paper presents the FAO catch data allocated to our global system of spatial cells for the year 2000. This sample output is indicative of the results achievable through the SimMap program which has previously been used to demonstrate the impacts of fishing on the marine ecosystems of the North and South Atlantic, including biomass and trophic levels, to calculate direct overlaps of fisheries with populations of marine mammals, and to illustrate the spatial distributions of catch values and energy consumption by fishing fleets. Using the SimMap program, anomalies in official fisheries landings reported by countries to the FAO have been detected and have led to revised global statistics and historical trajectories.

143. **Towards Sustainable Fisheries: Mapping Regional and Global Trends in Abundance and Catches**

D. Zeller, R. Watson, V. Christensen, J. Alder, M. Palomares, D. Pauly, (2003). 11pp.

mapping, fisheries, global, Atlantic

paper published in proceedings of the *Regional long-term changes in the spatial distribution, abundance and migration of pelagic and demersal resources.*, Tallinn, Estonia,

.

144. **Multiscale Decision Support for Aquatic Protected Area Placment.**

R. Watson, (2003). 191-195.

mpa, global, mapping, saup

http://www.ecomarres.com/downloads/APA.pdf

paper published in proceedings of the *Proceedings from the World Congress on Aquatic Protected Areas*, Cairns, Australia, August, 2002

Successful placement of protected areas not only relies on a myriad of local social factors relating to current resource users and jurisdictional boundaries, but also on the relevant scale spatial distribution and movement of species, ecosystems and habitats for which protection is sought. Equitable protection can be viewed as a problem with many spatial scales, and conventionally for some there has been little data available. A data mapping process (SimMap) was developed to support a large study on the effect of fishing on marine ecosystems (The Sea Around Us? project; [http://saup.fisheries.ubc.ca)](http://saup.fisheries.ubc.ca) and provides critical data at a number of scales, linking fine-scale ecosystem models (EcoPath/EcoSim/EcoSpace) in a nested fashion to whole ocean basin, and even global distributions of taxa and oceanographic processes. This system supports the spatial ecosystem modelling used to evaluate the impacts of protected areas, and also allows work within these ecosystems to be extrapolated over larger areas and the investigation of temporal changes.

145. **Use of Stranding Data to Test a Gis Approach for Mapping Large-Scale Distributions of Poorly Known Marine Mammal Species: An Example Using the Family Ziphiidae.**

K. Kaschner, R. Watson, C. MacLeod, D. Pauly, (2003).

marine mammal, model, mapping, distribution, whale

paper published in proceedings of the *Quantitative Seminar Series*, University of Washington, Seattle, Washington, USA.,

The delineation of geographic ranges for cryptic marine mammal species is often subjective and limited to roughly sketched outlines encompassing all known records. We developed a new, more quantitative approach to map the distribution of marine species based on existing knowledge about habitat preferences and demonstrate this approach on beaked whales (Ziphiidae, Cetacea), one of the least known families of mammals. We used available published information about species-specific habitat preferences with respect to depth, sea surface temperature and ice-edge association to assign species to broad-scale, quantified habitat categories. Using a raster-based GIS model, we related the quantified preferences to locally averaged oceanographic conditions. Predicted distributions closely matched published information about maximum range extents for most species, encompassing at least 90 % of all known sighting records. In addition, raster-based predictions provided more detailed information about the relative suitability of the environment for a species throughout its range. To test the validity of the approach, we developed a simulation model of ziphiid strandings using a global data set of residual ocean currents. Relative probabilities of strandings were generated based on two different input distributions: species-specific habitat suitability predictions and a uniform distribution based on published information. Simulated strandings based on habitat suitability predictions produced significant correlations with observed strandings for more than twice as many species (11 of 21 ziphiid species) as those generated based on uniform distributions (5/21). Thus, results provided support for our quantitative approach to map species distributions. The visualization of potentially important habitat areas based on this GIS approach will help to re-evaluate current assumptions and knowledge about marine mammal distribution. This in turn will help focus research efforts in the context of the impact of underwater noise pollution on ziphiids and other management issues.

146. **A Spatial Representation of the Tiger Prawn (Penaeus Esculentus) Fishery in Shark Bay, Western Australia**

N. G. Hall, R. A. Watson, (2000). 212-230.

prawn, shrimp, management, Western Australia, Australia, model, migration

http://www.ecomarres.com/downloads/NormPrawn.pdf

paper published in proceedings of the *Australian Society for Fish Biology Workshop Proceedings: Fish Movement and Migration*, Albury, Victoria, Australia, 1999

The fishery for brown tiger prawns, Penaeus esculentus, in Shark Bay, Western Australia, experienced reduced recruitment in the early 1980s. It is considered that this decline resulted from recruitment overfishing. The measures subsequently implemented to reduce fishing effort on the tiger prawns were constrained by the objective of maintaining the harvest of western king prawns, P. latisulcatus. which was the dominant species in the catch. A series of spatial closures was applied to different regions within the fihery in an attempt to reduce effort on brown tiger prawns, yet maintain catches of western king prawns. The closures were intended to take advantage of the spatial structure of the fishery and the migration that occurs between fishing grounds. Until now, a subjective approach has been used, in consultation with the fishing industry, in determining the appropriate closures. A compartmental delay-difference model has been developed to represent the spatial structure of the brown tiger prawn fishery and to describe the distribution of the prawns through consecutive months of the fishing season. In the absence of explicit inJonnation on the rates of migration between fishing grounds, the model represents the migration rates as parameters, and estimates these, together with catchability and recruitment parameters, from the observed monthly catch rates within the fishing grounds. Using this model, a more accurate time series of annual recruitment indices has been calculated for the Shark Bay tiger prawn stock.

147. **Computer Simulation of Fisheries Closures.**

R. Watson, C. T. Turnbull, (1997). 405-410.

shrimp, prawn, model, simulation, fisheries, closures, MPA

http://www.ecomarres.com/downloads/closesim.pdf

paper published in proceedings of the *Developing and sustaining world fisheries resources: the state of science and management. Proceedings of 2nd World Fisheries Congress.*, Brisbane Australia, Aug 1996

Simulation modelling was used to examine the benefits of seasonal and spatial closures of two prawn fisheries which differed in their recruitment patterns; one had a single recruitment pulse (annual) while the other had two each year (biannual). An optimization procedure was used to assign monthly fishing effort (within realistic constraints) which would maximize annual catch value. Reductions in values resulting from uncertainty in recruitment timing were examined. An 'ideal' pattern of monthly fishing effort for each fishery was fitted using an exhaustive search method because other methods could not find the global optimimum. Catch values resulting were used as a basis of comparison within each fishery with closure results. For the annual fishery, the best seasonal closure produced 98% of the value of the 'ideal', spatial closures 102%, and combined seasonal and spatial closures 104%. Relative values for the biannual fishery were similar except for combined closures which produced 116%. Generally, however, spatial closures outperformed combined and seasonal closures when recruitment timing was uncertain. Egg production was generally 30-40% of an unfished stock and was highest for combined closures.

148. **Maximising the Landed Value from Prawn Fisheries Using a Variation on the Simulated Annealing Algorithm**

R. Watson, N. R. Sumner, (1997). 864-868.

shrimp, model, optimisation, Western Australia, Australia, prawn

http://www.ecomarres.com/downloads/PrawnSim1.pdf

paper published in proceedings of the *International Congress on Modelling and Simulation*,

Simulation is used to improve the management of prawn fisheries by indicating patterns of fishing effort which prevent the harvest of under-sized animals, conserve sufficient breeding stock, and maximise the sustainable yield. Attempts to use conventional optimisation methods to find the optimum pattern of weekly fishing efforts have been ineffective because of the many extraneous local maxima. Through the use of global optimisation methods such as simulating annealing we have been able to find fishing effort patterns which maximise predicted catch values. Despite being continuous variables, the optimum levels of weekly fishing efforts usually assumed either values of zero or else the maximum fishing effort allowed. Sensitivity of the predicted maximum catch value and the pattern of fishing effort achieving this were examined for a range of parameter values representing the fishing (net selectivity and catchability) and biological (natural mortality and growth rate) processes. The greatest catch values obtainable were constant for a wide range of values of trawl net selectivities and catchability parameters, however, the optimum fishing season to obtain these maxima altered. In contrast, changes in biological parameters had a large effect on the maximum catch value despite compensation in the optimum pattern of weekly fishing efforts.

149. **Protecting Vulnerable Stocks in Multi-Species Prawn Fisheries.**

J. W. Penn, R. A. Watson, N. Caputi, N. Hall, (1997). 122-129.

shrimp, prawn, Western Australia, Fisheries

http://www.ecomarres.com/downloads/prawnfish.pdf

paper published in proceedings of the *Developing and sustaining world fisheries resources: the state of science and management. Proceedings of 2nd World Fisheries Congress.*, Brisbane Australia, Aug 1996

Information from the unusual collapse and rebuilding of individual penaeid stocks within the Western Australian multi-species trawl fisheries assists in developing population models for penaeids and identities potentially vulnerable prawn stocks. The Exmouth Gulf stock of Penaeus merguiensisi collapsed in the 1960s and has not recovered. The P. esculentus stocks in Shark Bay and Exmouth Gulf suffered recruitment overfishing during the early 1980s, but significant reductions in the fishing effort directed at this species have resulted in increased breeding stock and improved catches; spawning stock-recruitment relationships have been developed for the two P. esculentus stocks. No such relationship is clear for the Penaeus latisulcatus stock in Shark Bay, but the data suggest that recruitment may be influenced by an environmental effect at the time of recruitment. The ability of a fishery to exert high levels of pre-spawning fishing mortality is a common factor in penaeid fisheries showing recruitment overfishing. Local geography, the position of the fishery within a species range, the presence of other species in a fishery, and the catchability, appear to affect susceptibility to overfishing.

150. **Making Fishing Effort in the World Ocean Sustainable: Lessons from Historic Trends**

R. Watson, (2011).

paper presented at the *AAAS 2050: Will There Be Fish in the Ocean?*, Washington, D.C., U.S.A.,

effort, global, over-fishing, fisheries

.

151. **Are Global Marine Fisheries Starving Seabirds?**

M. Paleczny, R. W. Furness, E. Hammill, V. Karpouzi, M. LeCorre, A. W. Trites, R. Watson, D. Pauly, (2011).

paper presented at the *2nd International Marine Conservation Congress*, Victoria, Canada, 14-18 May 2011

seabird, impacts, global, diet, overlap

.

152. **Spatial Overlap between Marine Biodiversity, Cumulative Threats and Marine Reserves in the Mediterranean Sea.**

M. Coll, C. Piroddi, V. Christensen, V. Karpouzi, M. Paleczny, M. L. Palomares, J. Steenbeek, P. Trujillo, R. Watson, D. Pauly, C. Abouy, F. Guilhaumon, D. Mouillot, F. B. R. Lasram, C. Nicolle, W. W. L. Cheung (2011).

paper presented at the *2nd International Marine Conservation Congress*, Victoria, Canada, 14-18 May 2011

Mediterranean, mapping, biodiversity, impacts

.

153. **Global Changes in Body Size, Distribution and Productivity of Marine Fishes under Climate Change: Implications for Conservation**

W. W. L. Cheung, J. Dunne, V. W. Y. Lam, J. L. Sarmiento, R. Watson, D. Zeller, D. Pauly, (2011).

paper presented at the *2nd International Marine Conservation Congress*, Victoria, Canada, 14-18 May 2011

global, climate change, shrinkage

.

154. **Are Global Marine Fisheries Starving Seabirds?**

M. Paleczny, V. Karpouzi, P. O'Hara, R. Watson, D. Pauly, (2010).

paper presented at the *World Seabird Conference*, Victoria Canada, September 7-11, 2010

seabird, diet, overlap, fisheries, global

.

155. **Mean Trophic Levels and the Worm-Hilborn Collaboration**

T. Branch, R. Watson, E. Fulton, C. McGilliard, G. Pablico, D. Ricard, S. Tracey, (2010).

paper presented at the *American Fisheries Society*,

trophic level, Marine Trophic Index

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156. **Aquamaps**

K. Kaschner, J. S. Ready, E. Agbayani, J. Rius, K. Kesner-Reyes, P. D. Eastwood, A. B. South, S. O. Kullander, T. Rees, C. Close, R. Watson, D. Pauly, R. Froese, (2007).

paper presented at the *International Conference on Biodiversity Data Management*, Bedford Institute, Nova Scotia, Canada, October 2-4, 2007

biodiversity, database, mapping

.

157. **World Fish Catch Driven by Primary Production**

E. Chassot, S. Bonhommeau, F. Melin, O. Le Pape, R. Watson, D. Gascuel, (2007).

paper presented at the *PICES-ICES The effect of climate on basin-scale processes and ecosystems*,

climate change, Primary production, fisheries, impacts

.

158. **Global Fisheries: The Big Picture**

R. Watson, A. Kitchingman, (2006).

paper presented at the *Australian Society for Fish Biology*, Hobart, Australia,

global, fisheries

.

159. **The Direct and Indirect Contribution of Cephalopods to Marine Fisheries**

M. E. Hunsicker, T. E. Essington, R. Watson, R. Sumaila, (2006).

paper presented at the *American Fisheries Society*, Lake Placid, NY, U.S.A.,

invertebrate, global, cephalopod, fisheries

.

160. **Mapping Fisheries Catches and Related Indices of West Africa: 1950 to 2000**

R. Watson, (2005).

paper presented at the *Cartographie des prises halieutiques d’Afrique occidentale : 1950 à 2000 In Pêcheries maritimes, écosystèmes & sociétés en Afrique de l’Ouest : Un demi-siècle de changement, 24-28 juin 2002*, Dakar, Senegal, 2005

global, mapping, landings, statistics, impacts, Africa http://www.ecomarres.com/downloads/DakarWatson.pdf

A new approach is presented which allows broad regional landing statistics from FAO and other sources to be examined as detailed catch maps using avail-able knowledge of the distribution of commercial species and historical records of fishing access arrangements. Results are presented as time series composi-tions and as regional maps detailing changes since 1950 to 2000. These catches can be related to current exclusive economic zone boundaries and to the areas represented by ecological models (such as Ecospace), facilitating better use of landing statistics in economic, ecological and other analysis.

161. **Fish and More: A Global Seabird-Base Is Underway**

V. Karpouzi, R. Watson, D. Pauly, (2005).

paper presented at the *3rd FishBase Mini Symposium – Fish and More*, Thessaloniki, Greece,

seabird, database, fisheries, diet

.

162. **Trends in Fish Biomass Off Northwest Africa, 1960-2000.**

V. Christensen, P. A. Amorim, I. Diallo, T. Diouf, S. Guenette, J. J. Heymans, A. N. Mendy, M. Sidi, M. L. D. Palomares, B. Samb, K. A. Stobberup, J. M. Vakily, M. Vasconcellos, R. Watson, D. Pauly, (2005).

paper presented at the *Cartographie des prises halieutiques d'Afrique occidentale : 1950 à 2000 In Pêcheries maritimes, écosystèmes & sociétés en Afrique de l'Ouest : Un demi-siècle de changement, 24-28 juin 2002*, Dakar, Senegal, 2005

biomass, Africa, demersal, pelagic

http://www.ecomarres.com/downloads/FCRR_12(7)_p215.pdf

We estimate biomass trends for demersal and large pelagic fishes, (i.e., excluding small pelagic and mesopelagic fishes) based on 17 Ecopath models from Mauritania, Cape Verde, Senegal, the Gambia, Guinea, and Guinea-Bissau, Sierra Leone and the open waters of the central east Atlantic, made to represent various time periods during the second half of the 20th Century. We use a published method developed for estimating fish biomass in the North Atlantic, and modify it to account for the specificity of West African fisheries and ecosystems. We show that, overall, fish biomass as defined here (i.e., excluding low-trophic level and small fishes) has declined over the forty year period from 1960 by a factor of 13. An implication of our results is that further increase in fishing mortality in the region will not lead to increased catches but will only drive biomasses further down. The economic and political consequences of our findings are briefly discussed.

163. **Probing the Depths: Reverse Engineering Fisheries Landings Statistics**

R. Watson, J. Alder, V. Christensen, D. Pauly, (2004).

paper presented at the *AAAS - Place matters – geospatial tools for marine science, conservation and management'*, Seattle, Washington, U.S.A., February 10-13, 2004

mapping, landings, database, fisheries, global

.

164. **The Future for Global Fisheries: Several Scenarios for Action**

R. Watson, (2004).

paper presented at the *Marine Fish Conservation Network, Annual meeting*, Washington DC, U.S.A., June 2, 2004

global, fisheries, impacts

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165. **State of World’s Fisheries**

R. Watson, (2004).

paper presented at the *The World Summit on Salmon*, Vancouver, B.C. Canada,

salmon, global, fisheries, impacts

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166. **Fisheries Impact on Global Marine Biodiversity and Ecosystems: Inference from Large Heterogeneous Data Sets**

D. Pauly, R. Watson, (2004).

paper presented at the *International Conference on Marine Biodiversity Data Management*, Hamburg, Germany, 29 Nov – 1 Dec, 2004

biodiversity, fisheries, impacts, global, ecological impact

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167. **Mapping World-Wide Distributions of Marine Mammal Species Using a Relative Environmental Suitability (Res) Model (Poster)**

K. Kaschner, R. Watson, A. W. Trites, D. Pauly, (2004).

paper presented at the *International Conference on Marine Biodiversity Data Management*, Hamburg, Germany, 29 Nov – 1 Dec, 2004

marine mammal, distribution, global, habitat

.

168. R. A. Watson. (2016).

169. **A Global, Regional and National Developmental Status Assessment of Fishing Capacity and Fishing Effort from 1950 to 2012**

J. Bell, R. A. Watson, Y. Ye, (2015). "A Global, Regional and National Developmental Status Assessment of Fishing Capacity and Fishing Effort from 1950 to 2012," *Report prepared for the Food and Agriculture Agency of the United Nations* (University of Tasmania,

, http://www.ecomarres.com/downloads/FAOEffort.pdf

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170. **Catches [of the Chinese Distant- Water Fleet]**

D. Pauly, D. Belhabib, W. W. L. Cheung, A. Cisneros-Montemayor, S. Harper, V. Lam, Y. Y. Mai, F. Le Manach, K. M. Mok, L. van der Meer, S. Shon, W. Swartz, U. R. Sumaila, R. Watson, L. Zhai, D. Zeller, (2012). "Catches [of the Chinese Distant- Water Fleet]," *European Parliament, Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies - Fisheries.* (European Parliament, Brussels

China, distant water, fisheries, global, IUU

101111/faf.12032 http://www.ecomarres.com/downloads/China2.pdf

Republic of China for 2000 to 2011, using a newly assembled, large database of reported occurrence of Chinese fishing vessels in various parts of the world, and information on the annual catch of vessels by types. Given the unreliability of official statistics, uncertainty of results was estimated through a regionally stratified Monte Carlo approach which documents the presence and number of Chinese vessels in the Exclusive Economic Zones of countries and territories, then multiplies these by the expected annual catch per vessel. We find that China, which was known to over-report its domestic catch, massively under-reports the catch of its distant-water fleets. This catch, conservatively estimated at 4.6 million t·year-1 (±687,000 t·year-1) globally for 2000 to 2011 (compared to an average of 368,000 t·year-1 reported by China to FAO), corresponds to an ex-vessel landed value of 8.93 billion €·year-1 (± 1.53 billion). Chinese distant water fleets extract the largest catch in African waters, about 3.1 million t·year-1 (±690,000), followed by Asia (over 1.0 million t·year-1 ± 241,000), Oceania (198,000 t·year-1 ±31,000), Central & South America (182,000 t·year-1 ± 53,000) and Antarctica (48,000 t·year-1 ±26,000). The uncertainty of these estimates (± 1 standard deviation) is relatively high, but several sources of inaccuracy could not be fully resolved given the constraints inherent in the underlying data and method, which also prevented us from distinguishing between legal/reported and illegal, unreported or unregulated catch.

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171. **Spatial Expansion of Eu and Non-Eu Fishing Fleets into the Global Ocean, 1950 to Present.**

R. Watson, D. Zeller, D. Pauly, (2011). "Spatial Expansion of Eu and Non-Eu Fishing Fleets into the Global Ocean, 1950 to Present.," *Report prepared for WWF's Oceans & Coasts Program P.O. Box 7, 3700AA Zeist, NL (contact Dr. Reinier Hille Ris Lambers, Senior Marine Advisor).* (Fisheries Centre, University of British Columbia, Vancouver, Canada

spatial expansion, EU, effort, fleet, global

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172. **Fisheries Landings from Regional Seas**

R. Watson, (2011). "Fisheries Landings from Regional Seas," *Fisheries Centre Research Report* No. 19 (Fisheries Centre, University of British Columbia, Vancouver, BC, Canada

landings, global

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

The methods, through which global landings are reported to the Food and Agriculture Organization of the United Nations (FAO) by member countries, and by other international and national agencies, are presented, with emphasis on sources of uncertainties and attempts to overcome these. The results of this spatial allocation process are landing data on a ½° latitude by ½° longitude grid, covering the about 180,000 cells of the world’s ocean for 1950 to 2006, from which various, first- and second-order indicators can be derived for any area of the ocean, including Regional Seas.

173. **Value of Fisheries Landings in Regional Seas.**

W. Swartz, R. Watson, U. R. Sumaila, (2011). "Value of Fisheries Landings in Regional Seas.," *Fisheries Centre Research Report* No. 19 (UBC, Vancouver, BC(Canada),

value, price, landings

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

We describe a global ex-vessel fish price database, as required for understanding the economic behavior of

participants in the world's fisheries. We demonstrate its usefulness, in the Regional Sea context, using the

marine fisheries of the Eastern African Regional Sea as an example, by linking it to a spatially defined

catch database, which makes it possible to attach landed values to species in both time and space.

174. **Subsidies to Fisheries in Regional Seas**

U. R. Sumaila, A. S. Khan, A. J. Dyck, R. Watson, G. Munro, P. H. Tyedmers, D. Pauly, (2011). "Subsidies to Fisheries in Regional Seas," *Fisheries Centre Research Report* No. 19 (UBC, Vancouver, BC(Canada)

subsidies, fisheries

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

A summary is given of the approach that was used to compile a global database of government subsidies to fisheries. The estimates obtained were reasonable, as evidenced by their acceptance by the World Trade Organization and the World Bank. However, mapping these subsidies by Regional Sea is questionable, due to their large size, which results in subsidy intensities from socioeconomically disparate countries being pooled.

175. **Deriving Indicators for Regional Seas.**

S. Lai, D. Felinto, J. Steenbeek, J. Buszowski, R. Watson, D. Zeller, D. Pauly, V. Christensen, (2011). "Deriving Indicators for Regional Seas. ," *Fisheries Centre Research Reports* No. 19 (Fisheries Centre, University of British Columbia., Vancouver, Canada

indicator

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

The approach is presented, which was used to extract the mean, maximum and minimum values of various features in areas of the global ocean, and aggregate these to yield indicators relevant to the status of Regional Seas, with emphasis on their biodiversity and fisheries. This work, facilitated by the availability of several databases previously spatialized (in a ½° latitude by ½° longitude grid system) by the Sea Around Us project, also required a rigorous spatial definition of UNEP's Regional Seas, which had been lacking so far.

176. **Using 'Aquamaps' for Representing Species Distribution in Regional Seas.**

K. Kaschner, J. S. Ready, E. Agbayani, K. Kesner-Reyes, J. Rius-Barile, P. D. Eastwood, A. B. South, S. O. Kullander, T. Rees, R. Watson, D. Pauly, R. Froese, (2011). "Using 'Aquamaps' for Representing Species Distribution in Regional Seas.," *Fisheries Centre Research Report* No. The State of Biodiversity and Fisheries in Regional Seas (Fisheries Centre, University of British Columbia., Vancouver, Canada

distribution, mapping

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

AquaMaps (www.aquamaps.org) are the products of an on-line approach for generating distribution range maps of marine organisms, which currently covers over 10,000 marine species of fish, marine mammals and invertebrates, the intention being to eventually generate standardized range maps for all species in the oceans. These range maps can be used to generate check-lists or inventories of species occurrence in datapoor areas, e.g., in Regional Seas.

177. **Global-Warming Induced Changes in the Catch Potential of Regional Seas**

W. Cheung, V. Lam, J. L. Sarmiento, K. Kearney, R. Watson, D. Zeller, D. Pauly, V. Christensen, (2011). "Global-Warming Induced Changes in the Catch Potential of Regional Seas," *Fisheries Centre Research Report* No. 19 (UBC, Vancouver, BC(Canada),

climate change, catch

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

We projected changes in global catch potential for over one thousand species of exploited marine fish and invertebrates from the early to the mid 21st century, under conservative climate change scenarios. We show that climate change will lead to large-scale redistributions of global catch potential, with an average that may reach increases of 30–70% in high-latitude regions and a drop of up to 40% in the tropics. Moreover, maximum catch potential declines considerably in the southward margins of semi-enclosed seas, while it increases in poleward tips of continental shelf margins. Such changes are most apparent in the Pacific Ocean. Among the 20 most important fishing Exclusive Economic Zone (EEZ) regions in terms of their total landings, EEZ regions with the highest increase in catch potential by mid-century include Norway, Greenland, the United States (Alaska) and Russia (Asia). On the contrary, EEZ regions with the biggest loss in maximum catch potential include Indonesia, the United States (excluding Alaska and Hawaii), Chile and China. Many highly impacted Regional Seas, particularly those in the tropics, lie adjacent to countries which are socioeconomically vulnerable to these changes.

178. **Diversity of Commercially Exploited Fish and Invertebrates in Regional Seas.**

W. Cheung, V. Lam, M. L. Palomares, R. Watson, D. Pauly, (2011). "Diversity of Commercially Exploited Fish and Invertebrates in Regional Seas.," *Fisheries Centre Research Report* No. 19 (UBC, Vancouver, BC, Canada

biodiversity, fisheries, invertebrate

1198-6727, http://www.ecomarres.com/downloads/diversitycomm.pdf

Distribution range maps of commerically exploited species, defined as marine fishes and invertebrates that are listed in fisheries catch statistics submitted by member countries to the United Nations' Food and Agriculture Organization (FAO), plotted onto a global 1/2 degree latitude/longitude cell grid, can be used to characterize the diversity of commerically exploited species in Regional Seas. Some caveats are discussed, notably the fact that low-latitude countries tend to taxonomically over-aggregate their fisheries statistics.

179. **Climate-Change Induced Species Invasions and Extirpations in Regional Seas**

W. Cheung, V. Lam, J. L. Sarmiento, K. Kearney, R. Watson, D. Pauly, V. Christensen, (2011). "Climate-Change Induced Species Invasions and Extirpations in Regional Seas," *Fisheries Centre Research Report* No. 19 (University of British Columbia, Vancouver, BC, Canada

biodiversity, climate change

1198-6727, http://www.ecomarres.com/downloads/regional.pdf

Climate change will impact the pattern of marine biodiversity through, among other things, changes in species distributions. So far, however, global studies on climate change impacts on ocean biodiversity have been scarce to non-existent. Here, we show that climate change impact can be analyzed by projecting the distributional ranges of a large sample of exploited marine fish and invertebrates to the year 2050, by using a recently developed dynamic bioclimate envelope model. Our projections show that climate change may lead to numerous extirpations (i.e., local extinctions) in the sub-polar regions, the tropics and semienclosed seas. Simultaneously, species invasions are projected to be most common in the Arctic and the Southern Ocean. Jointly, extirpations and invasions result in a dramatic species turnover of over 60% of the present biodiversity, implying ecological disturbances that will likely reduce the ecosystem services that are presently provided by the various Regional Seas.

180. **Sharks in the Seas around Us: How the Sea around Us Project Is Working to Shape Our Collective Understanding of Global Shark Fisheries.**

J. Biery, M. L. Palomares, M. L., W. Cheung, R. Watson, S. Harper, J. Jacquet, D. Zeller, D. Pauly, (2011). "Sharks in the Seas around Us: How the Sea around Us Project Is Working to Shape Our Collective Understanding of Global Shark Fisheries.," *Sea Around Us Project, Report to Pew Environment Group* (Fisheries Centre, University of British Columbia, Vancouver, Canada

shark, global, saup

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181. **Fisheries: Investing in Natural Capital**

A. M. Bassi, J. P. Ansah, Z. Tan, A. J. Dyck, L. G. Kronbak, L. Huang, M. Bawumia, G. Munro, R. Arnason, N. Vestergaard, R. Hannesson, R. Chuenpagdee, T. Charles, W. Cheung, A. Cisneros-Montemayor, A. L. Iturriza, V. Lam, D. Pauly, W. Swartz, L. Teh, D. Schorr, R. Watson, D. Zeller, (2011). "Fisheries: Investing in Natural Capital," *Towards a green economy*. (United Nations Environment Programme,

fisheries, global

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182. **Construction and Potential Applications of a Global Cost of Fishing Database**

V. W. L. Lam, U. R. Sumaila, A. Dyck, D. Pauly, R. Watson, (2010). "Construction and Potential Applications of a Global Cost of Fishing Database," *Fisheries Centre Working Paper* (Fisheries Centre, University of British Columbia, Vancouver, B.C., Canada.

costs, fishing, database

1198-6727, http://www.ecomarres.com/downloads/fishcost.pdf

The development of a global database of fishing cost is first described and then an overview of fishing cost patterns at the national, regional and global scales is provided. This fishing cost database provides crucial economic information that is necessary for assessing the economics of global fisheries and is useful for incorporation into sustainable management. The database was organized into two broad cost categories, that is, variable and fixed costs, for 144 maritime countries. Together, these countries captured approximately 98% of global landings in 2005. The cost data is categorized into country and gear type combinations, and this structure allows the cost data to link to spatially defined catch database for future analysis in both spatial and temporal dimensions. Costs also varied between gear types with tuna longliner and dredge being the gears with the highest variable and total fishing costs. When comparing costs across FAO regions, Oceania is shown to have the highest unit variable cost. The global average variable and total cost per tonne of catch in 2005 is estimated to range between US$ 608 and US$ 1,356 and US$ 732 and US$ 1,605, with middle values of US$ 970 and US$ 1,155, respectively. We estimate the total annual global variable fishing cost to be in the range of US$ 58 – 129 billion with an average of US$92 billion per year in year 2005 dollars.

183. **Mapping Anthropogenic Drivers of Change for Biodiversity Conservation Planning in the Western Indian Ocean.**

E. Lagabrielle, J. Maina, L. Massé, M. Séré, R. Watson, (2009). "Mapping Anthropogenic Drivers of Change for Biodiversity Conservation Planning in the Western Indian Ocean.," *Indian Ocean Commission & World Wildlife Fund, Madagascar* (Indian Ocean Commission & World Wildlife Fund, Madagascar, Antananarivo, Madagascar

mapping, impacts, biodiversity, Indian Ocean, conservation

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184. **Adjusting for Context in Evaluating National Fisheries Statistics Reporting Systems**

D. Pauly, R. Watson, (2008). "Adjusting for Context in Evaluating National Fisheries Statistics Reporting Systems," *Fisheries Centre Research Report* No. 16 (Fisheries Centre, Univ. of British Columbia, Vancouver, Canada

statistics, landings

1198-6727, http://www.ecomarres.com/downloads/fcrr16-7.pdf

Fisheries management requires detailed catch time series. Thus, the effectiveness of countries' reporting system can be, in part, evaluated by the taxonomic resolution of the data they submit to annually to Food and Agriculture of the United Nation (FAO). However, the fish and invertebrate faunas in the Exclusive Economic Zones (EEZs) of these countries differ widely, as do the species that are exploited and considered important enough to be reported in fisheries statistics.

To adjust for the difference, an index of reporting performance was devised which is based, for each country, on the ratio of the reported taxa (numerators) relative to the number of commercial taxa whose distribution overlaps with at least 10% of its EEZ (denominator). Commercial marine taxa of fish or invertebrates are here defined as species, genera, families or higher group reported in the catch of at least one country in the FAO database, for any year from 1950 to the present. The result is a new Context-Adjusted Fisheries Statistics Indicator (STATrep).

Using the STATrep, New Zealand, Portugal and the US are the three countries that are performing best, while the worst performing countries are a group of mainly developing countries much of their catches as 'miscellaneous fishes', e.g., Myanmar. However, the STATrep appears to overcome the developed vs. developing country dichotomy, with e.g., Senegal, in West Africa, ranking 12th of 53.

The STATrep also appears to be suitable for tracking changes in the effectiveness of national fisheries reporting systems, except perhaps for countries with very small EEZs. This should, however, not affect the 53 countries that are being compared here, and which jointly account for 95 % of the world marine fisheries catch.

185. **Asymmetry in Latitudinal, Longitudinal and Bathymetric Distribution of Marine Fishes and Invertebrates.**

D. Pauly, W. W. L. Cheung, C. Close, S. Hodgson, V. W. Y. Lam, R. Watson, (2008). "Asymmetry in Latitudinal, Longitudinal and Bathymetric Distribution of Marine Fishes and Invertebrates.," *Fisheries Centre Research Report* No. 16 (Fisheries Centre, University of British Columbia, Vancouver, Canada

distribution, marine fishes, invertebrates

1198-6727, http://www.ecomarres.com/downloads/16-3-3.pdf

The distribution ranges of organisms, and marine animals in particular, are a manifestation of their environmental requirements, although they are often modified by the dynamics of prey and predators. Distribution range maps can also be used to infer where an activity occurs which requires the presence of a set of species, e.g., a fishery which targets them. The distribution of marine fishes and invertebrates serves as the basis for the mapping of fisheries by the Sea Around Us Project. Thus, accurate range maps are extremely important, and an earlier contribution by Close et al. (2006; FCRR 14(4): 27-37) reviews the step-by-step approach, and the assumptions used to predict the distribution of relative abundance of marine fishes and invertebrates from broad geographical limits, e.g., ocean basins, latitudinal limits, depth limits, etc., to relatively narrow polygons surrounding a number of ½ degree lat.-long. cells. Once established, such distributions, at least those referring to demersal fishes and invertebrates, can be interfaced with a map of sea bottom temperature, and inferred temperature preference profiles (TPP). These can be used, among other things, to verify the distribution ranges as predicted distributions should generate unimodal TPP, with the bulk of the distributions spanning a narrow range of temperature (~100 Celsius). As a relatively large fraction of the TPP that we obtained at first appeared bimodal, or exhibited a strong kurtosis, the assumption was revisited that the distribution of a species with regard to latitude can be simulated by an equal-sided triangle. It is shown here, for the cod (Gadus morhua), and generally for all our over 900 demersal species, that assuming a skewed triangular distribution, whose degree of skew is proportional to the temperature gradient from low to high latitude, generates more realistic distributions when compared to observed species distribution maps, although the narrowing of the uni-modal temperature probability distributions is relatively small. This correction will be implemented in all distribution ranges of demersal fishes and invertebrates in the Sea Around Us database, and used for catch allocation, and inferences on climate shifted distributions due to climate change.

186. **Modelling Seasonal Distribution of Pelagic Marine Fishes and Squids**

V. W. Y. Lam, W. W. L. Cheung, C. Close, S. Hodgson, R. Watson, D. Pauly, (2008). "Modelling Seasonal Distribution of Pelagic Marine Fishes and Squids," *Fisheries Centre Research Reports* No. 16 (Fisheries Centre, University of British Columbia, Vancouver, Canada

modelling, seasonal, distribution, pelagic, marine fishes, squids

1198-6727, http://www.ecomarres.com/downloads/16-3-2.pdf

The distribution of pelagic marine fishes and invertebrates varies seasonally. However, information on the seasonal variation of the distribution of most pelagic marine fishes and invertebrates is scarce. In this paper, seasonal changes in distribution ranges of commercially exploited pelagic fishes and invertebrates are predicted based on the existing Sea Around Us Project distribution, a prediction algorithm, the correlation between seasonal hanges in northsouth boundaries and sea surface temperature. In the northern hemisphere, in summer (July to September), mobile pelagic marine species tend to migrate to the northern part of their distribution range to avoid excessive temperature near the equator, while in winter (January to March), the same species will migrate southward to avoid the low temperature at higher latitudes. The converse applies to the southern hemisphere. The resulting distributions can improve the prediction of temperature preference profile of pelagic species which are important in evaluating the effects of global warming on their distribution ranges. However, this method of predicting summer and winter distributions of pelagic species can only be considered as an approximation as other factors such as food availability, salinity, rainfall and current are not included. On the other hand, such approximation appear reasonable, given the global scope of the application of the predicted seasonal distributions and the large number of evaluated species (> 160).

187. **Marine Fisheries**

K. Flower, A. Rodrigues, A. Balmford, R. Watson, (2008). "Marine Fisheries," *The Economics of Biodiversity and Ecosystems: Scoping the Science* (European Commission, Cambridge, UK

biodiversity, economics, ecosystem

, http://ec.europa.eu/environment/nature/biodiversity/economics/index_en.htm

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188. **Models of the World's Large Marine Ecosystems; Gef/Lme Gloabl Project Promoting Ecosystem-Based**

Approaches to Fisheries Conservation and Large Marine Ecosystems

V. Christensen, C. Walters, R. Ahrens, J. Alder, J. Buszowski, L. B. Christensen, W. Cheung, J. Dunne, R. Froese, V. Karpouzi, K. Kaschner, K. Kearney, S. Lai, V. Lam, M. L. D. Palomares, A. Peters-Mason, C. Piroddi, J. L. Sarmiento, J. Steenbeek, R. Sumaila, R. Watson, D. Zeller, D. Pauly, (2008). "Models of the World's Large Marine Ecosystems; Gef/Lme Gloabl Project Promoting Ecosystem-Based Approaches to Fisheries Conservation and Large Marine Ecosystems," *IOC Technical Series* (Unesco,

model, LME, Large Marine Ecosystem, Ecopath

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189. **Fisheries for Forage Fish**

R. Watson, J. Alder, D. Pauly, (2006). "Fisheries for Forage Fish," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

fishmeal, forage fish, global fisheries

1198-6727, http://www.ecomarres.com/downloads/Chpt1_14-3.pdf

Following a brief historical review of the emergence of fisheries for forage fish that are primarily destined for reduction, and their competition with fisheries for human consumption, an account is given of landing trends in various parts of the world, and catch maps are provided for the 1970s and 2000s which allow spatial and temporal comparisons. A brief account is also given of the changing species composition of the landings, the exploitation status of the fisheries, the trophic levels trends of species destined for reduction, the fuel consumption of the global fleet exploiting forage fish which are primarily small pelagics, the fishing gear they use, and the ex-vessel prices they fetch.

190. **Fuel Subsidies to Global Fisheries: Magnitude and Impacts on Resource Sustainability**

U. R. Sumaila, L. Teh, R. Watson, P. Tyedmers, D. Pauly, (2006). "Fuel Subsidies to Global Fisheries: Magnitude and Impacts on Resource Sustainability," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

subsidy, forage fish, fuel, global

1198-6727, http://www.ecomarres.com/downloads/FCRR14_6-2.pdf

It is generally accepted that global fisheries are grossly overcapitalized, resulting in overfishing in most of the world's fisheries. Fuel prices have recently seen significant increases. Given that fuel constitutes a significant component of fishing costs, it is obvious that, other things being equal, increasing fuel prices will reduce overcapacity and overfishing, because they will reduce the profits that can be made, thereby driving marginal fishers out of fishing. But, other things are hardly equal. Here, the willingness of governments to provide the fishing sector fuel subsidies reduce, if not completely negate, the conservation value of increasing fuel costs. The objective of this contribution is twofold. First, we explore the theoretical basis for the expectation that increasing fuel price faced by fishing enterprises will, everything being equal, reduce fishing pressure. Second, we estimate the amount of fuel subsidies (defined narrowly here as the price differential between what others and fishers pay in an economy) paid to the fishing sector by governments globally. Results from our study indicate that global fuel subsidies stand at between US$ 6±2 billion per year. This implies that, depending on how much of this subsidy existed before the fuel price increase, fishing enterprises can, in the aggregate, absorb as much as this amount of increase in their fuel budget before we begin to see any conservation benefits from fuel price increases.

191. **Subsidies to High Seas Bottom Trawl Fleets**

U. R. Sumaila, A. S. Khan, L. Teh, R. Watson, P. Tyedmers, D. Pauly, (2006). "Subsidies to High Seas Bottom Trawl Fleets," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

subsidy, trawl, global, high seas

1198-6727, http://www.ecomarres.com/downloads/FCRR14_6-3.pdf

The life spans of demersal species of fishes occurring in deep waters are much longer and their potential growth rates much lower than those of related shallow water species. As a result, deep-sea demersal fish species are more vulnerable to exploitation. This is because low growth rates relative to the available market discount rate for capital makes it desirable for fishing firms to mine, rather than sustainably exploit, these resources even in the absence of fisheries subsidies. However, it is common knowledge that governments around the world do provide subsidies to their fishing industries. The objective of this contribution is to estimate the global amount of subsidies paid to bottom trawl fleets operating in the high seas, i.e., outside of the Exclusive Economic Zones of maritime countries. Our study suggests that fisheries subsidies to these fleets stand at about US$152 million per year, which constitutes 15% of the total landed value of the fleet. Economic data for bottom trawlers suggest that the profit achieved by this vessel group is normally not more than 10% of landed value. The implication of this finding is that without subsidies, the bulk of the world's bottom trawl fleet operating in the high seas will be operating at a loss, and unable to fish, thereby reducing the current threat to deep-sea and high seas fish stocks.

192. **The Nature and Magnitude of Global Non-Fuel Fisheries Subsidies**

A. Khan, U. R. Sumaila, R. Watson, G. Munro, D. Pauly, (2006). "The Nature and Magnitude of Global Non-Fuel Fisheries Subsidies," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

subsidy, forage fish, global, fisheries

1198-6727, http://www.ecomarres.com/downloads/FCRR14_6-1.pdf

Fishery subsidies greatly impact the sustainability of fishery resources. Subsidies that reduce the cost of fisheries operations and those that enhance revenues make fishing enterprises more profitable than they would be otherwise. Such subsidies result in fishery resources being overexploited, as they contribute directly or indirectly to the build-up of excessive fishing capacity, thereby undermining the sustainability of marine living resources and the livelihoods that depend on them. In this contribution, fishery subsidies are identified and categorized, taking into onsideration the policy relevance of fishery subsidies worldwide, subsidy program descriptions, sources of funding, scope and coverage, annual total amounts, administering authority, and the recipients of the subsidy. Using this taxonomy, a database of subsidy programs reported in marine capture fisheries for 144 coastal countries was compiled spanning 1995 to 2005. From this, an annual estimate of subsidies paid to the fishing sector by governments globally is computed for 2000. This static estimate accounts explicitly for data gaps. Total global fishery subsidies were estimated at about US$26 billion for the eleven subsidy types identified in this study (excluding fuel subsidies). About 60% of this amount was provided by 38 developed countries and the remaining 40% by 103 developing countries. The proportion of estimated subsidies that contributed towards an increase in fishing capacity globally amounted to about US$15 billion, while subsidies that contributed to fisheries management and conservation programs were approximately US$7 billion. The remaining US$4 billion are defined as ugly subsidies, i.e., they may lead either to fisheries conservation or to overcapacity depending on the context. Japan and the EU were the highest subsidizers of their fisheries, with about US$4.2 billion and US$3.0 billion, respectively. The results from this study have policy implications for fisheries subsidy reforms at the on-going WTO negotiations on rules to eliminate subsidies that cause overcapacity, and in achieving sustainable fisheries management. In conclusion, three major areas are highlighted for future research, the impact of subsidies on: (i) resource exploitation, (ii) industrial profits, and (iii) food sufficiency and livelihoods.

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193. **Forage Fish Consumption by Marine Mammals and Seabirds**

K. Kaschner, V. Karpouzi, R. Watson, D. Pauly, (2006). "Forage Fish Consumption by Marine Mammals and Seabirds," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

fishmeal, forage fish, marine mammal, seabird

1198-6727, http://www.ecomarres.com/downloads/Chpt3_14-3.pdf

This contribution presents estimates of the amounts and distributions of small pelagic fishes (i.e., ‘forage fish’) consumed by the 115 species of marine mammals and the 351 species of seabirds known to feed in the world’s marine waters. The methods used for mapping the distribution of these predators and of their prey, detailed elsewhere, are briefly recalled. Marine mammals, in the 1990s, annually consumed about 20.2 million t of small pelagics, or roughly 12 % of their food consumption; for seabirds, the corresponding figures, also applying to the 1990s, are 12.1 million t of small pelagics and 12.5 % of their food consumption. Overall, we find that marine mammals and seabirds do not compromise human exploitation of small pelagics. On the other hand, reduced biomasses of small pelagics are a challenge for numerous species of marine mammals and seabirds.

194. **The Direct and Indirect Contributions of Cephalopods to Global Marine Fisheries**

M. E. Hunsicker, T. E. Essington, R. Watson, R. Sumaila, (2006). "The Direct and Indirect Contributions of Cephalopods to Global Marine Fisheries," *Global Ocean Ecosystem Dynamics* No. The role of squid in open ocean ecosystems (GLOBEC,

cephalopod, invertebrate, landings, global

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195. **Distribution Ranges of Commercial Fishes and Invertebrates.**

C. Close, W. L. Cheung, S. Hodgson, V. Lam, R. Watson, D. Pauly, (2006). "Distribution Ranges of Commercial Fishes and Invertebrates. ," *Fisheries Centre Research Reports* No. 14 (Fisheries Centre, University of British Columbia, Vancouver, Canada

range, distribution, fisheries, marine fishes, invertebrates, global

1198-6727, http://www.ecomarres.com/downloads/14-4-Close.pdf

Distribution ranges of commercial fish and invertebrates are required by the Sea Around Us Project for mapping of global fisheries catches. However, published ranges exist for only a small fraction of the 1231 taxa, composed of 923 species, 161 genera and 147 higher groups used in the latest version of the mapping process (Version 3.1, representative of catches from 1950 to 2003). This paper summarizes the methods employed by the Sea Around Us Project to reduce potentially global distributions to realistic ranges by identifying key ecological information for each of the 1231 commercial taxa, specifically: (i) presence in FAO area(s); (ii) latitudinal range; (iii) range-limiting polygons; (iv) depth range; and (v) habitat preferences. Furthermore, this paper presents an additional filter that outlines how (ii) and (iv) are used to correct the depth range for the effect of ‘equatorial submergence.’ Several examples are used to illustrate this process, notably the Florida pompano (Trachinotus carolinus) and the Silver hake (Merluccius bilinearis). Throughout this paper, the data sources emphasized include FishBase, other fish and invertebrate databases, and online information where applicable. In addition, simple heuristics are used to replace ecological information that is unavailable or missing. It should be noted that the Sea Around Us Project does not explicitly use temperature and primary production for any of the procedures discussed in this paper. The purpose of this is to allow for subsequent analyses of distribution ranges using these variables.

196. **Global Ex-Vessel Fish Price Database: Construction, Spatial and Temporal Applications**

R. Sumaila, A. D. Marsden, R. Watson, D. Pauly, (2005). "Global Ex-Vessel Fish Price Database: Construction, Spatial and Temporal Applications," *Fisheries Centre Working Paper* (Fisheries Centre, University of British Columbia, Vancouver, Canada

price, database, global

1198-6727, www.fisheries.ubc.ca/workingpapers/index.htm

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197. **On the Exploitation of Elasmobranchs, with Emphasis on Cowtail Stingray Pastinachus Sephen (Family Dasyatidae)**

D. Pauly, S. Booth, V. Christensen, W. L. Cheung, C. Close, A. Kitchingman, M. L. D. Palomares, R. Watson, D. Zeller, (2005). "On the Exploitation of Elasmobranchs, with Emphasis on Cowtail Stingray Pastinachus Sephen (Family Dasyatidae)," *Fisheries Centre Working Paper* (Fisheries Centre, University of British Columbia, Vancouver, B.C., Canada

rays, fisheries, global, stingray

1198-6727, http://www.ecomarres.com/downloads/FCWP_2005_07.pdf

Characterized by over-exploitation of many of the commercial stocks, the fisheries of the world are in a crisis. In particular, pressure is extremely strong on predators at the top of marine food webs. Typically, the fisheries for these predators, once initiated, last about 10-15 years, i.e., from the time the fisheries start developing and catches are minimal to the time catches have peaked, and then collapsed. This is particularly true for elasmobranchs (mainly sharks, rays and skates), which are characterized by high longevity and low fecundity. Among the elasmobranchs, large rays are particularly susceptible to trawl fishing, although in most countries, they are not targeted, but form part of the by-catch. In fact, one of the first documented extirpations (i.e., local extinctions) of marine fish was of a ray in the Irish Sea. As a large long-lived elasmobranch, the Cowtail stingray (Pastinachus sephen) is extremely susceptible to overfishing, and is widely caught as by-catch of the shrimp trawl fisheries throughout its Indo-Pacific range. The development of targeted fisheries for this stingray, driven by the luxury leather market demand for its skin for processing into pens, wallets, boots, etc., will accelerate the depletion to which this and allied species are already subjected. None of the countries in which the Cowtail stingray is abundant have fisheries management systems in place for this or any other species of rays. It can be expected that the directed fisheries will expand geographically from their center in Southeast Asia, as the original stocks are depleted (as has been the case for fisheries elsewhere), leaving devastated stocks behind. The fisheries science community has no way of ensuring that this exploitation can be made sustainable. It is questionable, therefore, that a demand for luxury products should be allowed to expand that may devastate this and related species, and the ecosystems of which they are a part.

198. **Patterns of Species Richness in the High Seas**

W. Cheung, J. Alder, V. Karpouzi, R. Watson, V. Lam, C. Day, K. Kaschner, D. Pauly, (2005). "Patterns of Species Richness in the High Seas," *Secretariat of the Convention on Biological Diversity, Montreal, Technical Series* No. 20 (Secretariat of the Convention on Biological Diversity, Montreal, Canada

biodiversity, distribution, global, high seas

, http://www.ecomarres.com/downloads/biodiv.pdf

Maps of the species richness in the high seas are presented, which are based on the distribution of individual species of marine invertebrate and vertebrate groups, complemented with maps of genera and families of invertebrates and fishes. High seas refers to marine areas outside the 200-mile exclusive economic zones (EEZs) and continental shelf areas, or other described national jurisdictions.We considered known latitudinal and longitudinal gradients of the distribution of species richness (declining from the equator, and from a global center of species richness about Indonesia) where appropriate. Maps of the known locations of cold-water corals and seamounts are also presented. There is suggestive evidence that cold-water coral are associated with seamounts. If validated, this would allow predicting the existence of far more cold-water corals sites than so far documented. Both habitat types are threatened by trawling. Lastly, a map of the distribution of threatened non-fish vertebrates is provided. Together, these maps indicate marine biodiversity in the high seas to be richly patterned, with some of these patterns helping to identify areas in need of protection such as seamounts, and the high seas of the Southwest Pacific.

199. **Chapter 18: Marine Fisheries Systems**

A. Bakun, S. Heileman, K.-H. Kock, P. Mace, W. Perrin, K. Stergiou, U. R. Sumaila, M. Verrios, K. Freire, Y. Sadovy, V. Christensen, K. Kaschner, M.-L. Palomares, P. Tyedmers, C. Wabnitz, R. Watson, B. Worm, (2005). "Chapter 18: Marine Fisheries Systems," *Ecosystems and Human Well-being: Current State and Trends. Millennium Ecosystem Assessment.* (

climate change, assessment, biodiversity

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200. **Fishing Gear Associated with Global Marine Catches**

R. Watson, E. Hoshino, J. Beblow, C. Revenga, Y. Kura, A. Kitchingman, (2004). "Fishing Gear Associated with Global Marine Catches," *Fisheries Centre Research Reports* No. 12 (Fisheries Centre, University of British Columbia, Vancouver, Canada

global, fishing gear, trawl

1198-6727, http://www.ecomarres.com/downloads/12-6.pdf

Fishing gears, instrumental to the fishing process, exert direct but often poorly documented impacts on marine communities and habitats. A database is described here that associates all global catch with fishing gear types allowing for the analysis of global fishing patterns. The fine spatial detail of the Sea Around Us project?s catch database allows for the construction of maps showing subtle changes in the use of fishing gears annually since 1950. These maps are particularly useful to help assess the impact of fishing gears such as bottom trawls and dredges, which have been shown to have significant impacts on marine communities. Maps included in this report chronicle the expansion of these and other gears in ways that will inform debate over their impacts, and proved critical information to inform policy development and management choices.

201. **Exploitation Patterns in Seamount Fisheries: A Preliminary Analysis**

R. Watson, T. Morato, (2004). "Exploitation Patterns in Seamount Fisheries: A Preliminary Analysis," *Fisheries Centre Research Reports* No. 12 (Fisheries Centre, University of British Columbia, Vancouver, Canada

seamount, fisheries

1198-6727, http://www.ecomarres.com/downloads/SeamountReport.pdf

Serious stock depletion on continental shelves helped create new pressure for alternative fishing grounds. In particular, seamounts were among those ?newly? targeted ecosystems that have been intensively fished since the second half of the 20th century. But what are the seamount fisheries? How have their catches changed in recent years? Can we map where these catches are taken? This paper describes the progress of this work. Most seamount species are also found on the continental slope, making the allocation of reported catches to specific seamounts difficult. Thus, future mapping of landings will require species distributions that allow proportioning of catches between slope areas and those taken on seamounts. Catches of fishes identified as mostly occurring on seamounts only began in 1967, initially with the Orange roughy fishery. The catches of these species have only continued because new seamounts with harvestable stocks were discovered as fisheries collapsed, and because new stocks or species were targeted. A pattern of successive rapid development and decline is evident. While the percent of fisheries that collapsed is somewhat similar for seamount species and those not associated with seamounts, it is obvious that those fisheries that are based on species found only on seamounts have collapsed with greater frequency and had poorer recovery. This points towards the conclusion that not only seamount fisheries, but deep-water trawling in general, may not be sustainable in the long term.

202. **Mass Balance of Atlantic Oceanic Systems**

M. Vasconcellos, R. Watson, (2004). "Mass Balance of Atlantic Oceanic Systems," *Fisheries Centre Research Reports* No. 12 (Fisheries Centre, University of British Columbia, Vancouver, Canada

ecosystem, model, Atlantic

1198-6727, http://www.ecomarres.com/downloads/massbalance.pdf

This report describes the methods and data sources used to estimate ecological parameters and to construct mass-balance models of oceanic ecosystem of the Atlantic using the Ecopath with Ecosim (EwE) software. Six models were constructed representing oceanic ecosystems of the North, Central and South Atlantic for the 1950s and the late 1990s (1997-1998). The first section of this report characterizes some of the fundamental characteristics of oceanic ecosystems which were captured in a model template for oceanic areas. The subsequent sections are devoted to individual functional groups, composed of species or group of species that share similar ecological functions, habitats and demographic characteristics, or represent important fisheries resources, such as tunas and swordfish. The last sections describe the approach used to balance the models in EwE and the adjustments made to the late 1990s model so that it could represent the ecosystem state in 1950.

203. **Ecological Geography as Framework for a Transition toward Responsible Fishing**

D. Pauly, R. Watson, V. Christensen, (2003). "Ecological Geography as Framework for a Transition toward Responsible Fishing," *Responsible Fisheries in the Marine Ecosystem.* (Food and Agriculture Organization of the United Nations,

ecology, mapping, saup

, http://www.ecomarres.com/downloads/Ecological%20geography%20Iceland%20conf.pdf

Meeting the widely expressed requirement that fisheries should somehow be managed on an ?ecosystem basis? implies that fisheries-relevant ecological processes, and the fisheries themselves, need to be documented in the form of maps. This allows recovery, in intuitive fashion, of at least some of the many dimensions of the complex ecosystems in which the fisheries are embedded. The implied transition, in fisheries science, from bivariate time series, to maps as major heuristic devices has a number of implications ? some obvious, some less so ? of which a number are here discussed and illustrated.Amongthe issues covered are: (i) the requirement for a consensus taxonomy of large marine ecosystems; (ii) the need to construct fisheries catch maps in the absence of positive records of what was caught where; (iii) the proper identification of one?s audience; and (iv) the mapping of marine protected areas and reserves. The seriousness of the fisheries crisis is emphasized, and the case is made that fisheries, if ever they are going to achieve some measure of sustainability ? however defined ? ultimately will have to be limited not only through the amount of effort they can effectively deploy, but also limited in space, leading to a change to the defaults under which fisheries operate, currently set such that all aquatic wildlife can be exploited, if under some restrictions.

204. **The Rights to Fish - an Ecological Critique of Individual Transferable Quotas.**

U. R. Sumaila, R. Watson, (2002). "The Rights to Fish - an Ecological Critique of Individual Transferable Quotas.," *Policy proposals and operational guidance for ecosystem-based management of marine capture fisheries* (Resource Conservation Programme, WWF Australia, Australia

conservation, marine, ITQ, quota

, http://www.ecomarres.com/downloads/WWF_EBM.pdf

Individual Transferable Quotas (ITQs) are exclusive and transferable rights to harvest a given portion of the total allowable catch of fish. They are one form of 'rights-based management' used to manage the allocation of resources adn interactions between users of marine ecosystems. Fishery managers establish total allowable catch levels (TACs), and divide this among individual fishers or fishing companies in the form of individual harvest quotas, usually a percentage of the TAC. ITQs are transferable by being sold or purchased on the open market. In theory, ITQs can create de facto property rights. The accomplishments and problems of ITQ are discussed.

205. **Policy Simulation of Fisheries in the Hong Kong Marine Ecosystem.**

W. L. Cheung, R. Watson, T. J. Pitcher, (2002). "Policy Simulation of Fisheries in the Hong Kong Marine Ecosystem.," *Fisheries Centre Research Reports* No. 10 (Fisheries Centre, University of British Columbia, Vancouver, Canada

modelling, ecosystem, policy, Hong Kong, China

1198-6727, http://www.ecomarres.com/downloads/10-2.pdf

Alternative fishery management policies under different policy objectives for the 1990s Hong Kong waters ecosystem were explored using a newly developed simulation model named ?policy simulator? under the Ecopath with Ecosim software. Scenarios, which aim to maximize the economic output, the social output, the ecological output, and a compromise between the above three outputs were simulated under different vulnerability settings. Results suggested that policy simulations that aimed to maximize economic and social strategy were sensitive to vulnerability setting. Results from simulations aimed to maximize ecological stability and the compromise scenario are generally consistent between different vulnerabilities, and suggested that fishing effort of all fishing sectors and all except P4/8 fishing sectors, respectively, should be reduced. The study also demonstrated that the economic and social outputs decrease when policy objective focuses increasingly on maximizing ecological stability. The results are consistent with general observations of fisheries management. It is suggested that the ?policy simulator? offers excellent insights into management trade-offs in an ecosystem context.

206. **The Marine Fisheries of China: Development and Reported Catches.**

R. Watson, L. Pang, D. Pauly, (2001). "The Marine Fisheries of China: Development and Reported Catches.," *Fisheries Centre Research Reports* No. 9 (Fisheries Centre, University of British Columbia, Vancouver, Canada

landings, China, saup

1198-6727, http://www.ecomarres.com/downloads/fullchina.pdf

This document presents two interrelated studies on the marine fisheries of the People?s Republic of China, both emphasizing, if in different ways, the magnitude of the catches reported throughout the 1990s. The first study, by Lillian Pang and Daniel Pauly, titled ?Chinese Marine Capture Fisheries from 1950 to the late 1990s: the Hopes, the Plans, and the Data,? reviews the history and development of Chinese marine fisheries since 1950, notably the extremely strong increase of reported catches from the mid-1980s on. The case is then made, based on the design of the statistical reporting system, and the professional motivation structure of local fisheries officials, that over-reporting is likely to be the cause for much of the nominal catch increase. Supporting evidence is provided by similar overreporting in other food-producing sectors, by various other fisheries studies (notably of catch per effort trends), the stressed state of Chinese coastal ecosystems, and the proclamation, by China?s Central Government, of a zero-growth policy designed to undermine local over-reporting and to restructure the fisheries sector. The second study, by Reg Watson, titled ?Spatial Allocation of Fisheries Landings from FAO Statistical Areas 61 and 71? describes a rule-based, computer-intensive algorithm developed by the author and associates to map the world?s fisheries catches in ½ degree cells. The resulting global map, which suggests the Chinese shelf and adjacent waters to be as nearly as productive as the Peruvian coastal upwelling system, was broadly reproduced by a General Additive Model that used depth and primary production as predictor variables. The catches reported from Chinese marine waters explained a large fraction of the differences between observed and predicted values, strongly suggesting that current Chinese nominal catches are greatly over-reported. These two studies thus confirm each other, and provide strong evidence that indeed, Chinese national statistics over-report marine catches from Chinese waters. The internal adjustments that correcting for the underlying deficiency of the statistical reporting system will require are not investigated, and nor are the food policy issues implied by these findings. It is clear, however, that these issues are serious, for both China and the rest of the world, thus explaining, if need be, the critical tone of our studies. It is hoped that the Chinese authorities, international bodies, concerned scientists and others will find harmonious ways to resolve these issues.

207. **Mapping Fisheries Landings with Emphasis on the North Atlantic**

R. Watson, A. Gelchu, D. Pauly, (2001). "Mapping Fisheries Landings with Emphasis on the North Atlantic," *Fisheries Centre Research Reports* No. 9 (Fisheries Centre, University of British Columbia, Vancouver, Canada

mapping, landings, saup

1198-6727, http://www.ecomarres.com/downloads/CatchMaps_Watson1.pdf

Fisheries landing statistics from broad statistical reporting areas were mapped as catches with a resolution of 30 minutes of longitude x 30 minutes of latitude. The procedure involved the progressive disaggregation of the statistics, firstly to provide poorly defined records with a better taxonomic identity, and secondly by using a rule-based process involving databases of known distributions of taxa, oceanographic features and of the areas where reporting countries are permitted to fish, in order to spatially disaggregate the data. Maps prepared for reporting years 1950 until 1999 showed trends in the spatial distribution of fisheries catches, provided a valuable means of examining other questions such as interactions between fishing and marine mammals, and provided descriptions of the global catch from large marine ecosystems. Catch maps prepared for the North Atlantic are illustrated and were used in the formation of ecological models and in the preparation of maps of catch value.

208. **Key Features of Commercial and Recreational Fisheries Statistics from the Us Atlantic Coast.**

T. Ryan, R. Watson, D. Pauly, (2001). "Key Features of Commercial and Recreational Fisheries Statistics from the Us Atlantic Coast. ," *Fisheries Centre Research Reports* No. 9 (Fisheries Centre, University of British Columbia, Vancouver, Canada

landings, USA, fisheries, saup

1198-6727, http://www.ecomarres.com/downloads/USA_Ryan1.pdf

This contribution briefly describes the major features of the database of fisheries catches from the Eastern USA, from Maine in the North to the tip of the Florida peninsula in the South, i.e., excluding the Gulf of Mexico. The two major databases for commercial and recreational catches created by the National Marine Fisheries Service are described, along with a number of related efforts both at Federal and States? level. Also, some of the scattered contributions devoted to estimating discards, and misreported catches are discussed, with emphasis on their potential by the Sea Around Us project for generating high-resolution catch maps.

209. **Developing and Assessing Techniques for Enhancing Tropical Australian Prawn Fisheries and the Feasibility of Enhancing the Brown Tiger Prawn (Penaeus Esculentus) Fishery in Exmouth Gulf.**

N. R. Loneragan, D. J. Die, G. M. Kailis, R. Watson, N. Preston, (2001). "Developing and Assessing Techniques for Enhancing Tropical Australian Prawn Fisheries and the Feasibility of Enhancing the Brown Tiger Prawn (Penaeus Esculentus) Fishery in Exmouth Gulf.," *Revised Final Report to FRDC* (Australia

shrimp, Australia, aquaculture, model

, http://www.ecomarres.com/downloads/1998-222-DLD.pdf

The prawn trawl fishery in Exmouth Gulf, Western Australia, is well managed and harvests a mixture of penaeid prawns. Catches of the high value, brown tiger prawn Penaeus esculentus have comprised about 36% of the annual catch in the 1990s. However, annual catches of tiger prawns are now about half the level they were in the 1970s and fluctuate markedly, from about 200 to 680 t. These changes in catch create uncertainty in the supply of prawns for export markets and force fishing and processing operators to have excess capacity to deal with good years. Managers, fishing industry and researchers are considering the option of enhancing the natural recruitment of brown tiger prawns by releasing juveniles in wild nursery areas to reduce natural fluctuations and increase the average annual catch. This collaborative project (CSIRO, Fisheries WA, MG Kailis Group of Companies) assessed the feasibility of stock enhancement of tiger prawns in Exmouth Gulf by: developing a bioeconomic model, examining the risks of changes in the genetic composition and introducing disease to the wild population of tiger prawns, and identifying further work that would be needed before stock enhancement should proceed. This is the first stage in several stages that would lead to stock enhancement of tiger prawns in Exmouth Gulf. The project was initiated through a workshop of all project participants in Perth in July 1998.

210. **Modeling and Mapping Trophic Overlap between Marine Mammals and Commercial Fisheries in the North Atlantic.**

K. Kaschner, R. Watson, V. Christensen, A. W. Trites, D. Pauly, (2001). "Modeling and Mapping Trophic Overlap between Marine Mammals and Commercial Fisheries in the North Atlantic.," *Fisheries Centre Research Reports* No. 9 (Fisheries Centre, University of British Columbia, Vancouver, Canada

marine mammal, modelling, range, trophic, impacts

1198-6727, http://www.ecomarres.com/downloads/Mammal_Kaschner1.pdf

The impact that fishing operations may have on marine mammals and other components of marine ecosystems is a major concern today. Fisheries, in addition to causing by-catch mortalities, affect marine mammals through direct and indirect competition for the same food sources. Our goal was to assess the potential trophic impact of fisheries on mammal populations in the North Atlantic by quantifying the overlap in resource exploitation in space and time using high-resolution modeling and mapping. We developed a relatively simple model to estimate feeding requirements (specified by food type) and population biomass of all North Atlantic marine mammal species. Main model input parameters were population abundance, sex-specific mean body mass, standardized diet compositions, and weight-specific feeding rates. A spatial model was constructed using a geographic information system to link annual food consumption estimates to the corresponding species-specific, rasterized distributional ranges. Spatially explicit food intake (expressed as proportions of total food intake per ½ degree latitude/longitude square) was further refined by incorporating information about habitat preferences and feeding patterns. Superimposing the geographically matching fisheries catches (generated by a similar rule-based model) allowed the calculation of overlap between fisheries catches and marine mammal consumption. The model indicates that, in the North Atlantic, total food consumption of marine mammals in the 1990s was three times higher than total fisheries catches. However, spatially disaggregating consumption and specifying intake by food type showed actual resource overlap to be quite low. Areas of high overlap in the North Atlantic are concentrated along the East coast of North America (35° ? 53° N) and in European shelf waters. This visualization of geographical ?hotspots? of marine mammal-fisheries interactions may help to identify areas of conflict, realized or potential. Hence the meta-analysis approach taken here may serve as a useful management tool in the context of defining marine mammal critical habitat and efficient MPAs design.

211. **Estimating Fish Abundance in the North Atlantic, 1950 to 2000**

V. Christensen, S. Guenette, S. Heymans, C. J. Walters, R. Watson, D. Zeller, D. Pauly, (2001). "Estimating Fish Abundance in the North Atlantic, 1950 to 2000," *Fisheries Centre Research Reports* No. 9 (Fisheries Centre, University of British Columbia, Vancouver, Canada

biomass, saup, landings, Atlantic

1198-6727, http://www.ecomarres.com/downloads/estabundance.pdf

We estimate the biomass of high trophic-level fish in the North Atlantic at a spatial scale of 1⁄2 degree latitude by 1⁄2 degree longitude over the time period from 1950 to 1999, based on 23 spatialized, ecosystem models, each constructed to represent a given year or short period from 1880 to 1998. We extract over 7800 data points that describe the abundance of high trophic-level fishes as a function of year, primary production, depth, temperature, latitude, ice cover, and catch composition. We then use a multiple linear regression to predict the spatial abundance for all North Atlantic spatial cells for each year from 1950 to 1999. The results indicate that the biomass of high trophic-level fishes has declined by two-thirds during the fifty-year period. Catches increased from 2.4 to 4.7 million tonnes annually in the late 1960s, and subsequently declined to below 2 million tonnes annually in the late 1990s. The fishing intensity for high trophic-level fishes tripled during the first half of the time period, and remained high during the last half of the time period. We estimate that the high trophic-level species contributed 53% to the value of total fish landings in 1950, and that this declined to 29% by the end of the century. Comparing the fishing intensity to similar measures from 35 assessments of high trophic-level fish populations from the North Atlantic, we conclude that the trends in the two data series are similar. Our results raise serious concern for the future of the North Atlantic as a diverse, healthy ecosystem; we may soon be left with only low trophic-level species in the sea.

212. **The Basis for Change: Part I . Reconstructing Fisheries Catch and Effort Data**

R. Watson, S. Guenette, P. Fanning, T. J. Pitcher, (2000). "The Basis for Change: Part I . Reconstructing Fisheries Catch and Effort Data," *Fisheries Centre Research Reports* No. 8 (Fisheries Centre, University of British Columbia, Vancouver, Canada

bycatch, catch, effort

1198-6727, http://www.ecomarres.com/downloads/watson03.pdf

Rational examination of marine policy requires an analysis of changes in the abundance of species and marine community structure with respect to past policy decisions. Abundance estimates themselves rely heavily on catch and effort statistics. There are official statistics of fish landings for many fisheries of the world. Fishing effort data is generally less available. Unfortunately, for a variety of reasons, landings data do not always reflect actual catches well. For example, discarded catches are left out of official statistics, which developed primarily to demonstrate the value of commercial landings. Illegal or unmandated (not subject to regulated reporting requirements) catches are seldom documented except in candid stock assessment discussions of major species. Through an exhaustive compilation of existing data sources and with the assistance of expert local consultants and/or partnerships, we can develop databases that present a more complete and accurate picture of the catches of marine species, including those of limited commercial significance. The importance of this process is demonstrated by our example from the Canadian North Atlantic fisheries. In this case a partnership arrangement has allowed the inclusion of the discards of fishes, crustaceans and marine mammals based on observer data. An outline of the database required to include and document 'adjustments' to official statistics is presented. This work will be extended to the entire North Atlantic region and beyond.

213. **The Basis for Change 2: Estimating Total Fishery Extractions from Marine Ecosystems of the North Atlantic**

T. J. Pitcher, R. Watson, (2000). "The Basis for Change 2: Estimating Total Fishery Extractions from Marine Ecosystems of the North Atlantic," *Fisheries Centre Research Reports* No. 8 (Fisheries Centre, University of British Columbia, Vancouver, Canada

bycatch, IUU, saup

1198-6727, http://www.ecomarres.com/downloads/8-2.pdf

The reason for estimating total extractions of fish is to able to account for their impacts on marine ecosystems. Such an evaluation has not been attempted before, since ecosystem modelling techniques suitable for this purpose have only recently become available. Putting a figure on total extractions entails the difficult task of estimating, in addition to reported landings, discards, illegal, and unmandated catches, including disreported catches. These unreported extractions cast various types of shadows, many of which may be tracked and estimated quantitatively. Official figures often have an implicit assumption that such categories are zero, an unacceptable option for an ecosystem-based project. Some examples of adjustments for unrecorded catches are reported. We describe an innovative, well-funded NGO that tracks and publicizes illegal catch in the Southern Ocean and which may provide a model for other areas of the world such as the North Atlantic. We present an adjustment procedure based on a simple spreadsheet, divided into categories of unreported annual catch. Adjustment factors are based on reports from observers, confidential correspondents and on information published in a variety of sources. Over time the adjustment factors respond to changes in regulatory regime and hence the incentives and disincentives to mis-report. Once in place, this method provides preliminary estimates that may be refined without disruption. Preliminary estimates, set up as a ?straw man? for Atlantic Canada, suggest average figures since 1960 of around 30% for unreported extractions of cod and over 100% for herring. Although at first sight an adjustment procedure for illegal catch may appear controversial, we argue that such transparency is not only an essential part of a new fisheries regime that mimimizes deleterious impacts to marine ecosystems, but is also in conformity with the treatment of other kinds of fraud in contemporary society.

214. **Mapping Fisheries onto Marine Ecosystems: A Proposal for a Consensus Approach for Regional, Oceanic and Global Integrations**

D. Pauly, V. Christensen, R. Froese, A. Longhurst, T. Platt, S. Sathyendranath, K. Sherman, R. Watson, (2000). "Mapping Fisheries onto Marine Ecosystems: A Proposal for a Consensus Approach for Regional, Oceanic and Global Integrations," *Fisheries Centre Research Reports* No. 8 (Fisheries Centre, University of British Columbia, Vancouver, Canada

mapping, global, saup, ecosystem, LME

1198-6727, http://www.ecomarres.com/downloads/8-2.pdf

Research on ecosystem-based fisheries management, marine biodiversity conservation, and other fields requires appropriate maps of the major natural regions of the oceans, and their ecosystems. It is proposed here that a classification system proposed by T. Platt and S. Sathyendranath and implemented by A.R. Longhurst, defined largely by physical parameters, and which subdivides the oceans into four ?biomes? and 57 ?biogeochemical provinces? (BGCPs), could be merged with the system of 50 Large Marine Ecosystems (LMEs) identified by K. Sherman and colleagues, which would represent subunits of the provinces. This arrangement enhances each of the systems, and renders them mutually compatible. For the LMEs, subprovinces are pragmatically defined to serve as a framework for the management of coastal fisheries, and other purposes, while the BGCPs have rigorous physical definitions, including borders defined by natural features. Moreover, incorporating the 50 defined LMEs into the framework of BGCPs will allow straightforward scaling-up of LME-specific flow estimates (including fisheries catches) up to basin and ocean scales. The combined mapping will allow the computation of GIS-derived properties such as temperature, primary production, etc., and their analysis in relation to fishery catch data for any study area. A further useful aspect of the proposed scheme is that it will enable us to quantify the EEZ of various countries in terms of the distribution of marine features (e.g., primary production, coral reef areas) which has yet to be traightforwardly aassociated with coastal states. Applications to shelf, coral reef and oceanic fisheries, and to the mapping of marine biodiversity are briefly discussed.

215. **The Western Australian Scallop Industry**

D. C. Harris, L. M. Joll, R. A. Watson, (1999). "The Western Australian Scallop Industry," *Fisheries Research Reports* No. (Fisheries Western Australia, Perth, Australia

scallop, Western Australia, Australia

, http://www.ecomarres.com/downloads/scallop.pdf

Five separate commercial fisheries target the saucer scallop, Amusium balloti (Bernadi 1861) in Western Australian waters. While the average annual catch from these fisheries is around 600 tonnes of scallop meat, past catches have been highly variable with annual landings ranging from 150 to 4,400 tonnes of meat worth between $2 and $59 million. Consequently, scallops represent one of the larger single-species fisheries operating in Western Australia (WA). A.

balloti has a distribution spanning most of the WA coast, from Broome in the north around to Esperance in the south. Despite this extensive distribution, saucer scallops tend to be restricted to areas of bare sand in the more sheltered environments found in the lee of islands and reef systems, and are consequently found in commercially viable amounts in only five locations in WA. The five WA fisheries that target scallops (with average annual landings in brackets) are: the Shark Bay Scallop Managed Fishery (541 t), the Abrolhos Islands and Mid-West Trawl Managed Fishery (121 t), the south coast (15 t), the South-West Trawl Managed Fishery (11 t), and the Nickol Bay Prawn Managed Fishery (4 t). The majority of the annual catch is exported as frozen scallop meat to Asia, Europe and the United States of America; while a small portion is marketed directly to the public via local retail outlets. As with catches, wholesale market prices have fluctuated dramatically over the last 10 years, plummeting from $16/kg in 1987 to $8.50/kg by 1991, before steadily improving to peak at $28.50/kg in 1995. This variation has arisen primarily in response to product availability and condition. The primary scallop fisheries operate in Shark Bay and around the Abrolhos Islands. Commercial fishing commenced in these fisheries in the late 1960s with moderate catches reported. Following a period of low catches in the mid 1970s, landings increased significantly during the late 1970s and early 1980s, mainly due to increased recruitment and fishing effort. Further advancements in processing methods and marketing strategies, and an associated increase in profitability, attracted even more vessels to the fisheries with further increases in effort. Subsequently, both were declared limited entry fisheries (now termed Managed Fisheries under the Fish Resources Management Act 1994). The Abrolhos Islands and Mid-West Trawl Fishery and Shark Bay Scallop Fishery were declared limited entry fisheries in 1986 and 1987 respectively. As A. balloti is an active swimmer, otter trawling is favoured. Vessels fishing for scallops in WA employ demersal otter trawl gear with strict controls placed on the vessels (boat units) and associated trawl gear (size restrictions) that can be used in each of the fisheries. These controls are designed to limit the total fishing effort to acceptable levels in order to maintain adequate spawning stocks, and to target those scallops at a size and age when the meat is in a premium condition for market. Research into the biological and environmental aspects of WA scallop stocks and their commercial exploitation has been carried out by Fisheries WA since the late 1960s. This research has centred on maximising the economic returns from the available scallop resource, while managing its use and harvesting at ecologically sustainable levels. Research initiatives have included pre-season surveys to monitor the strength of recruitment to seasonal scallop stocks; the monitoring of environmental influences, such as the Leeuwin Current, and their effects on scallop populations; and the provision of detailed catch data via voluntary logbook programs and statutory monthly fishermen?s returns.

216. **Ecosim and Mpas: A Quasi-Spatial Use of Ecosim**

R. Watson, C. J. Walters, (1998). "Ecosim and Mpas: A Quasi-Spatial Use of Ecosim," *Fisheries Centre Research Reports* No. 6 (Fisheries Centre, University of British Columbia, Vancouver, B.C., Canada.

mpa, ecosim, model

1198-6727, http://www.ecomarres.com/downloads/6-2.pdf

While the first version of Ecosim (Walters et al. 1997) offered many facilities to mana-gers, it did not provide a means of describing the spatial relations of biomass and fishing mortalities which are required to examine the potential impacts of marine protected areas (MPAs). To overcome this, we devised a simple modification to Ecosim which allows the biomass of Ecopath groups to be partitioned into two portions with exchange processes operating between them.

217. **Assessment of Hong Kong’s Inshore Fishery Resources.**

T. J. Pitcher, R. Watson, A. Courtney, D. Pauly, (1998). "Assessment of Hong Kong’s Inshore Fishery Resources.," *Fisheries Centre Research Reports* No. 6 (Fisheries Centre, University of British Columbia, Vancouver, B.C., Canada.

Hong Kong, China, Fisheries

1198-6727, http://www.ecomarres.com/downloads/6-1.pdf

This work aims to determine the exploitation status of Hong Kong's inshore fishery resources, and the likely impact of management measures on the coastal ecosystem. This report describes results of the assessment work performed by the Fisheries Centre, UBC, between April 1996 and December 1997. Biomass and catch have been estimated by season and sector with survey data: from regular monthly samples of benthic resources using a prawn trawl, from samples of pelagic resources using a purse seine, and from catch estimated from an interview survey of fishers. Benthic biomass is also estimated in 18 spatial sampling strata. Prawns are included but the work does not cover shellfish. Total inshore resource biomass is estimated as about 9000 tonnes annual average (= 4.9 tonnes km-2), of which 85% is comprised of pelagic species. There is a strong seasonal pattern, seen most strongly in the pelagic species, but also present in benthic resources, with total biomass peaking at over 27,000 tonnes (= 15 tonnes km-2) in August and dipping to 1700 tonnes (= 0.9 tonnes km-2) in February. These results are subject to uncertainties in estimating swept areas and in extrapolating from more detailed work on individual species. Based on estimating the probability distribution of the catch rates of individual vessels in seven gear sectors and by species, the total catch in Hong Kong waters is estimated as 14,700 tonnes (7.8 tonnes km-2). A detailed breakdown of this catch by gear sector and species is provided. Very wide confidence limits reflect a high variance in individual vessel catch rates, and the results are subject to considerable uncertainty deriving from the adoption of an interview protocol to estimate catch. Detailed assessments of exploitation status have been carried out for 17 individual species, four of which are crustaceans. Growth parameters and mortality parameters have been fitted to survey data, and age data derived from otolith readings. Growth is fitted by least squares techniques, length frequency analysis, and estimates take account of many published values from the literature. Mortality includes total mortality, estimated largely by cohort slicing, offshore migration with age for certain demersal species, estimated by a novel method, and present fishing mortality calculated by two alternative methods. Yield- and biomass-perrecruit analyses have been employed to evaluate exploitation status. Uncertainties have been explicitly defined and addressed through confidence limits placed on most estimates using Monte Carlo simulation techniques. Twelve of the 17 species are heavily overexploited, while the remainder, principally the small high-turnover species, fall into the fully exploited category. Very approximate sustainable yield estimations based on calculating unexploited biomass suggest that catches of larger and slower-growing species might be roughly doubled with optimal management. A major uncertainty is the equilibrium assumption made by all of these methods, that recruitment will not be greatly affected by increases in abundance. Multi-species bioeconomic analysis for the trawl fishery, based on parameters from the individual species, conflates the assessment optima for the individual species in terms of their relative value. The results suggest that long term yield for the 17 species might be roughly doubled by increasing mesh size, but are sensitive to assumptions made in estimating relative recruitment factors among the species. A trophic mass-balance model of the Hong Kong inshore ecosystem is constructed from information derived from the analysis and from the literature. The model includes shellfish, marine mammals, and all living components of the system. The model is used to predict the impact of six scenarios of changes in management on the relative abundance of sectors of the resource. Halving the current fishing mortality results in considerable benefits for all fishery sectors, and those with a conservation focus such as marine mammals. The full benefits of such a policy may, however, take a decade to be realised.

218. **Fishing Patterns of the Torres Strait Fleet.**

R. Watson, P. J. Blyth, P. Channells, (1990). "Fishing Patterns of the Torres Strait Fleet.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

fisheries, Torres Strait, prawn, shrimp, Australia

, http://www.ecomarres.com/downloads/TSChp3.pdf

Commercial prawn trawling has occurred in Torres Strait since 1974 and now produces 1000 tonnes annually (Section 1). Three main species of penaeid prawns are taken commercially: Penaeus esculentus, the brown tiger prawn, Metapenaeus endeavouri, the endeavour prawn and P. longistylus, the red spot king prawn. P. esculentus and M. endeavouri together make up 90% of prawn landings for Torres Strait. P. esculentus dominates prawn catches and are the most sought after because the highest export prices are paid for this species. Fishing effort in the Torres Strait Prawn Fishery is concentrated in the early months of the year. This coincides with a peak in recruitment of small P. esculentus (Section 5). Prior to implementation of seasonal closures to fishing, fishing effort was more evenly applied throughout the year. The Torres Strait Prawn Fishery is subject to an international treaty which calls for joint catch-sharing and management arrangements between Australia and Papua New Guinea. Total allowable catch quotas, closed fishing seasons, vessel and gear restrictions and closed areas are employed in its management. The geographical extent of the fishery, the location of those areas currently closed and the areas of national jurisdiction are shown in Figure 1. Fisheries management requires detailed catch and effort data over a long time so that trends can be observed and possible population changes can be predicted, and the disaster of a failed fishery hopefully avoided. The Northern Prawn Fishery (NPF) logbook data is the only source of information which permits analysis of spat~al and temporal trends of catch and effort in the Torres Strait Prawn Fishery (Section 2). Logbook records provide total effort (hours trawled) and catch (kg) data for P. esculentus, M. endeavouri, P. longistylus, and other unidentified species of prawns at a spatial resolution of about 11 km2. Records are available from 1980 to the present. This study examines the spatial and temporal fishing patterns of the Torres Strait prawn fleet from 1980-86 based on NPF logbook records and relates these fishing patterns to P. esculentus recruitment patterns (Section 5).

219. **Prawn Fishery Simulation Yield Model.**

R. Watson, D. J. Sterling, (1990). "Prawn Fishery Simulation Yield Model.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, prawn, fisheries, Australia, management, closure

, http://www.ecomarres.com/downloads/TSChp12.pdf

Managers of fisheries have always sought to predict the consequences of any management measure before it is introduced. Even broad predictions have proven extremely difficult to make and, mistakes in predictions can be costly to the industry and possibly the long term durability of the fishery. The industry expects management measures to be precise. For example the optimum dates for seasonal closures are expected to have an accuracy measured in weeks, if not days. Many of the management measures being employed on prawn fisheries in Northern Australia are novel in their application, for example, seasonal closures to protect small prawns have been in use for less than ten years in northern Australia. Few if any experimental controls have been used to establish the effectiveness of these measures. Large inter-year variations in prawn numbers occur naturally and can complicate long-term assessments. In response to industry concern, several different management regimes have been used in successive years, making the explanation of results extremely difficult because of their possible interactions. To assess the response and elasticity of a fisheries' potential to withstand fishing pressure it is usually necessary to employ widely varying levels of exploitation and then observe the response. This means some degree of calculated under fishing exploitation and over fishing exploitation within the fishery. To be successful these 'experiments' have to be large in scale and extend for several years. The very idea of costly manipulation of a viable important fishery is, at least for the present, politically unacceptable. This means that researchers are asked to help managers decide on strategies without the benefit of the type of data from the system which would allow statistical predictions to be made. They must therefore employ data from other fisheries. Fisheries from which data is available are often from temperate regions, and all too often are failed fisheries and not ideal for comparison with a tropical prawn fishery. There is one other tool researchers and managers can employ. This tool is simulation modelling. A fisheries biologist can estimate a number of important biological and population parameters from direct measurement, experimentation, or from the scientific literature. These can be combined with information gathered from economists, commercial processors and fishermen to produce a series of rules and relationships. Such controls often govern the fishery through various limiting factors such as the number of vessels, the available searching time, the biology of the key species, or the economics of the products. One or more of these aspects can be combined using the computational powers of computers in a simulation of the fishery. These computer simulations often allow for graphical or tabular display of the results so that all potential users can visualise the results and gain some understanding of the interplay between the many complex relationships underlying the model. Several types of computer simulation models exist. As the name implies they are meant to simulate the fishery. Given suitable input such as the numbers and sizes of animals recruiting into the fishery, models can produce estimates of potential outcomes. These may be landings, numbers of animals the following year, or even net profits. Most of these simulation programs are based on dynamic models. Dynamic models attempt to model the passage of time in the life of the fishery. Some programs model time on a continuous basis, while most models use discrete time units. Units of years are applicable only to comparitively long-Iived animals. For prawns, units of months or even weeks are more appropriate. The time scale most appropriate is dependent on the generation time of the key species as well as the detail available in the input data, and the precision required of the predictions. Many models use fixed rules to relate the input data to outcomes and do not allow for chance circumstances, these are deterministic models. Others attempt to simulate the natural uncertainty in the reaction of one factor in the fishery to others, or the certainty or potential error in the input data. These models allow for random or pseudo-random processes to occur. These stochastic models produce different results every time they are used even if the same input data is used. While this produces a more realistic approximation of the natural situation, it requires additional information on the rules which regulate how this variation or randomness occurs. When stochastic models are used, it is common to reuse the computer model a number of times, through the process of Monte Carlo simulations, in order to extract the average result. In addition to the average outcome, stochastic models also allow the range of expected results to be determined. Models can be either extremely complex or 'reductionist' in nature and attempt to desc~ibe all knowable aspects of the animals' biology and the fishery in fine detail, or they can be general or 'holistic' in approach and deal with only the generalised net or overall affects. They can attempt to explain the relationship between all parameters that can be measured and attempt to predict all aspects of the fishery, or they can use only some of the available data to predict only one result such as the net profit. Modelling has been employed to great effect by Somers (1985) to predict the optimum opening date for the Penaeus merguiensis, banana prawn fishery in the Gulf of Carpentaria. Somers (1985) used information on prawn prices and prawn growth rates, together with weekly size surveys, to predict when harvest would maximise the gross profits of prawn fishermen. Sluczanowski (1984) used historical catch data and existing fisheries models to optimise (through modelling) population parameters for the Spencer Gulf prawn fishery of P. latisulcatus, the western king prawn. These parameters were then used in a subsequent model, which had an economic framework, to find management measures which would optimise total industry profits. The deterministic model that will be described below is not as complex as that used by Sluczanowski (1984) in the Spencer Gulf, and as yet has not been elaborated to produce economic parameters other than gross catch values. This model was originally developed to simulate the growth, immigration, emigration and mortality processes of juvenile P. esculentus, brown tiger prawns, in nursery areas of Torres Strait. 1t was then extended to include the adult or commercial phase of the life cycle, and to include the other two commercial species in Torres Strait, Metapenaeus endeavouri, endeavour prawn, and P. longistylus, redspot king prawn. It has already been employed to make crude predictions of the effects of differing seasonal closure periods on prawn catch values. With modification and further sophistication this model can be used to meet many of the prawn fishery managers future needs.

220. **General Introduction.**

R. Watson, J. E. Mellors, (1990). "General Introduction.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, Torres Strait, Australia, prawn, fisheries

, http://www.ecomarres.com/downloads/TSChp1.pdf

Torres Strait is a tropical body of water lying between the tip of the Cape York peninsula and the south coast of Papua New Guinea and bordered on the east and west by the Coral Sea and Arafura Sea respectively (Figure 1). The strait is shallow, usually less than 15 m deep. It extends 100 km north-south and 20 to 60 km east-west (Wolanski 1986). This region has extensive coral reefs, numerous coral cays and some continental islands. There are more than 70 islands throughout the Straits' 8 000 km2 sea area. Seventeen of these are inhabited by Islander communities (Bain 1986). The largest reefs in Torres Strait are the Warrior Reefs which extend for 65 km roughly north-south, bisecting the region and separating the Coral Sea to the east from the Arafura Sea to the west. Torres Strait is separated from the deeper waters of the Coral Sea by a ribbon of reefs which are a continuation of the outer Great Barrier Reef. Immediately to the east of the Warrior Reefs is the Great North East Channel. This channel is 20-40 m deep and continues as far as Papua New Guinea making it important as an international shipping route. It is this region where most of the Torres Strait fisheries are located (Anon. 1987a).

221. **Velvet Prawns (Metapenaeopsis Spp) of Torres Strait**

R. Watson, A. Keating, (1990). "Velvet Prawns (Metapenaeopsis Spp) of Torres Strait," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, prawn, Australia, biology, Torres Strait, velvet prawn

, http://www.ecomarres.com/downloads/TSChp8.pdf

Records of prawn catches in Torres Strait were poorly recorded during the developmental years of the prawning industry. Information collected by officers of the Northern Fisheries Unit in Cairns shows that in 1973-74 about ten prawn trawlers regularly fished Torres Strait, producing an annual catch of between 100 and 120 t. Catches consisted of mainly Penaeus esculentus, brown tiger prawns, and also Metapenaeus endeavouri, endeavour prawns. Prices at this time averaged $1.20 kg-1 for tiger prawns and $1.00 kg-1 for endeavour prawns. These vessels fished mainly from June to December in Torres Strait, after the end of the P. merguiensis, banana prawn, season in the Gulf of Carpentaria. Following ratification of the Torres Strait Treaty between Australia and Papua New Guinea in 1985 a management area, the Torres Strait Protected Zone (TSPZ), was defined under the jurisdiction of the Protected Zone Joint Authority (Section 1 - Figure 1). Although legally distinct from the two adjacent prawn fisheries, the Northern Prawn Fishery (NPF) and the Queensland East Coast Prawn Fishery, management of the Torres Strait Prawn Fishery has been run as part of the East Coast Prawn Fishery. With the introduction of joint management of Torres Strait fisheries with Papua New Guinea it became important to examine existing catch data for historical trends. The introduction of prawn catch quotas required by the Torres Strait Treaty relied on past catch records. This section collates historical catch data and examines trends in catch and effort.

222. **Commercial Prawn Catches in Torres Strait**

R. Watson, P. Channells, P. J. Blyth, (1990). "Commercial Prawn Catches in Torres Strait," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

fisheries, Torres Strait, Australia, prawn, shrimp, landings, catch, statistics

, http://www.ecomarres.com/downloads/TSChp2.pdf

RRecords of prawn catches in Torres Strait were poorly recorded during the developmental years of the prawning industry. Information collected by officers of the Northern Fisheries Unit in Cairns shows that in 1973-74 about ten prawn trawlers regularly fished Torres Strait, producing an annual catch of between 100 and 120 t. Catches consisted of mainly Penaeus esculentus, brown tiger prawns, and also Metapenaeus endeavouri, endeavour prawns. Prices at this time averaged $1.20 kg-1 for tiger prawns and $1.00 kg-1 for endeavour prawns. These vessels fished mainly from June to December in Torres Strait, after the end of the P. merguiensis, banana prawn, season in the Gulf of Carpentaria. Following ratification of the Torres Strait Treaty between Australia and Papua New Guinea in 1985 a management area, the Torres Strait Proteded Zone (TSPZ), was defined under the jurisdiction of the Proteded Zone Joint Authority (Sedion 1 - Figure 1). Although legally distind from the two adjacent prawn fisheries, the Northern Prawn Fishery (NPF) and the Queensland East Coast Prawn Fishery, management of the Torres Strait Prawn Fishery has been run as part of the East Coast Prawn Fishery. With the introdudion of joint management of Torres Strait fisheries with Papua New Guinea it became important to examine existing catch data for historical trends. The introduction of prawn catch quotas required by the Torres Strait Treaty relied on past catch records. This sedion collates historical catch data and examines trends in catch and effort.

223. **General Discussion.**

R. Watson, (1990). "General Discussion.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, prawn, Torres Strait, Australia

, http://www.ecomarres.com/downloads/TSChp13.pdf

This report presents some of the results from three years of research in Torres Strait. Some of the sections cover research which is presently ongoing and therefore are truly provisional in nature, while other sections have been reported in full as those phases of our research are completed. All sections presented in this interim report are esselltial to meeting our project's objectives {Section 1), as we could not restrict our research to surveys of adult commercial catches and historical studies of the fishery. It was necessary to study aspects of adult reproduction and juvenile development and to initiate tagging studies to understand and elucidate the life-cycle of the commercial prawn species Tagged prawns also allowed migration and growth rates to be monitored. It was necessary to investigate the use and performance of various survey gear to quantify estimates of juvenile and adult prawn numbers. Though this work was not an end in itself, it increased our understanding of prawn behaviour and revealed the potential sources of error in our survey estimates. Velvet prawns are not fished commercially in Torres Strait as they are in other north Queensland fisheries. We included them in our study for a two-year period because they were numerous, they are important to many other fisheries in the Indo-Pacific region, and they are of potential commercial value in Torres Strait. This work is now complete and it greatly increased our understanding of these species. Our surveys for juvenile prawns in seagrass areas often captured large numbers of other species, most notibly smaller fish species. Some of these are known to be major predators of juvenile commercial prawns. By retaining these fish specimens from beam trawl samples we were able to greatly expand our knowledge of potential prawn predators and of the community structure of seagrass habitats. Gathering information on the basic biological parameters of the commercial prawn species is time consuming. Often there is no completely satisfactory way of assessing the precision of our estimates of important things such as growth rates. A few years study of such a complex system as the Torres Strait Prawn Fishery does not allow much insight into the variability of these parameters between areas, years, and sometimes species. Though there is a strong desire for us to continue to improve our estimates and our understanding of the processes involved, this refinement would ultimately occur at the expense of our commitment to fisheries managers who require information on the relative merits of management options in real time. Key biological or population parameters can be combined with historical data in new or existing models of the fishery. The creation of these models test our understanding of the system. Our models can be refined as our understanding develops and through this process we can redirect our existing research to gather further information on key parameters or processes, or initiate research on important components that have been overlooked. We can use our models to test the possible impacts of different management scenarios once our models adaquately represent our understanding of the system and produce predictions which can be verified. Though the model predictions can often not be tested directly, they nevertheless represent our best estimate of the possible outcome of a management measure given our understanding of the fishery. In this way we can provide fisheries managers with the best information possible on which to base management decisions.

224. **Experimental Beam Trawls for Sampling Juvenile Prawns.**

C. T. Turnbull, R. A. Watson, (1990). "Experimental Beam Trawls for Sampling Juvenile Prawns.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

trawl, prawn, shrimp, seagrass, Torres Strait, Australia

, http://www.ecomarres.com/downloads/TSChp10.pdf

Small fine-meshed beam trawls have been used for conventional sampling of juvenile penaeids in seagrass areas (Coles and Lee Long 1985). As juvenile penaeids are nocturnally active, beam trawl sampling for them occurs at night for a set time or on a trawl track generally marked by lighted buoys. Many factors can affect the efficiency of beam trawls such as water depth, lunar intensity and the type of substrate or sediment being trawled over.

Sediments associated with seagrass nursery habitat sampled by Coles and Lee Long (1985) in the Gulf of Carpentaria were usually fine and silty. Sediments of Torres Strait nursery areas (Section 4) are coralline and punctuated by pieces of dead corals weighing several kilograms. This rough substrate interferes with the efficiency of a conventional beam trawl. Low tides at night on the reef-platform nursery areas of Torres Strait made daytime time sampling of juvenile penaeids in this region necessary (Section 4). Alternative sampling gear was designed for daylight sampling, which incorporated a higher clearance from the bottom to minimise the effect df rough terrain on the trawl gear.

A variety of gear has been used to sample prawns. Allen and Hudson (1970) described a sledmounted suction device which they employed to quantitatively sample young pink shrimp, Penaeus duorarum duorarum. They found that samples from their suction device compared favourably with those from a more conventional, hand-pulled frame trawl.

Penn and Stalker (1975) described and tested an "active" beam trawl which operated by pumping jets of water into the substrate. This action washed inactive buried prawns into the path of the net. Their design allowed quantitative daylight samples of nocturnally active juvenile prawns. Their beam trawl used a large collecting bottle on the cod end of their net which proved ineffective in substrates with a high volume of organic material such as dead seagrass.

Electricity has been used to improve catches of fish (McRae and French, 1965), prawns (Pease and Seidel, 1967), and lobsters (Saila and Williams, 1972). It is used routinely in the mariculture harvest of prawns such as Penaeus japonicus in Japan (Lewis and Carrick, 1987). It also can be used for daytime harvest of nocturnally active animals. Electric sampling gear has an added advantage. It can be designed to limit the retention of vegetation and sediment in the collecting bag by relying on the involuntary movement of prawns influenced by pulsed current rather than through the mechanical disturbance of the bottom.

In the present study three alterative beam trawls were tested to compare their efficiency. A conventional beam trawl designed for nighttime use was compared with a water jet beam trawl, and an electric beam trawl both designed for daytime use.

225. **Trawl Gear Performance Trials.**

D. J. Sterling, J. E. Mellors, R. Watson, (1990). "Trawl Gear Performance Trials.," *Torres Strait prawn project: A review of research 1986-88* (Queenasland Fisheries, Brisbane, Australia

trawl, shrimp, Australia, performance

, http://www.ecomarres.com/downloads/TSChp11.pdf

An accurate estimate of abundance is essential for fisheries management. Abundance estimates are often limited, due to insufficient information regarding the catch efficiency of the sampling gear. A measure of sampling gear efficiency will enable a realistic estimation of abundance. Trawl sampling gear efficiency, is the proportion of animals retained in the net relative to the total number in the path of the trawl (Kjelsohn and Johnson 1978). Estimating the efficiency of the sampling gear often causes serious problems for the analysis of trawl survey data. Gear efficiency involves many complex variables that are often insufficiently understood to predict their cumulative effects. The efficiency of trawl sampling gear varies not only for each species but also for different size classes and with varying environmental conditions (Kjelsohn and Johnson 1978). This unmeasured variability in trawl sampling gear efficiency, results in an error in estimating population size. Measuring this error remains a major and largely unresolved challenge in fishery science. Selectivity is closely related to gear efficiency and includes components of net mesh selectivity and fish or prawn behaviour. Mesh selectivity is the variation in fishing mortality with age, which is the differential escape of certain sizes of fish or prawns after they enter the mouth of the net (Gulland 1983). Both efficiency and selectivity describe in some way the performance of gear. The distinction made is that efficiency is a measure of the gear's catch relative to the total population present in the area swept by the net. Mesh selectivity is a measure of the gear's catch relative to the number of prawns that entered the mouth of the net. Gear efficiency includes the effects of mesh selectivity and any other processes of selectivity that occur when fish or prawns are initially stimulated from the sea bed into the mouth of the trawl. " Errors that occur in these calculations affect the estimates of absolute abundance and the shape of length-frequency distributions. Errors in length-frequency distributions are due to the size-specific nature of sampling trawl gear efficiency. Errors in estimates of absolute abundance are due both to the size-specific nature of the trawl, and to species-specific factors such as diurnal and seasonal variations in behaviour. Other factors that affect trawl efficiency are associated with the physical aspects of the fishing gear itself (Table 1). These factors have an importance that is often not fully appreciated in fisheries research. It is imperative that these factors are closely monitored during survey work to ensure that inter-sample variation of trawl efficiency is minimized. Commercial trawl gear designs compromise gear efficiency to achieve a practical and safe operation. The designs are selective for commercial species and sizes. They may be strongly biased against catching trash species and collecting debris even to the extent of having a negative effect on their commercial catch.If using commercial gear in fisheries research it may be necessary to be aware and correct for any bias that may exist. We conducted two separate experiments for efficiency and selectivity in order to investigate sample bias. Experiment 1 was designed to measure the size-specific trawl efficiency. Experiment 2 investigated mesh selectivity in greater detail. Experiment 1 is reported in full. The results presented for Experiment 2 incorporate data from only the first two monthly surveys and provides a preliminary examination of the selectivity performance of a standard port net relative to a small mesh starboard net.

226. **Reproductive Biology of Penaeus Esculentus (Haswell, 1879) and Metapenaeus Endeavouri (Schmitt, 1926) in Torres Strait.**

J. A. Keating, R. Watson, D. J. Sterling, (1990). "Reproductive Biology of Penaeus Esculentus (Haswell, 1879) and Metapenaeus Endeavouri (Schmitt, 1926) in Torres Strait.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, Australia, Torres Strait, reproduction, biology, brown tiger prawn, NPF

, http://www.ecomarres.com/downloads/TSChp6.pdf

In the past, management of the Torres Strait Prawn Fishery has relied on the reproductive biology and larval and juvenile abundance information on Penaeus esculentus, brown tiger prawn, from the Northern Prawn Fishery and the Queensland East Coast Prawn Fishery. Seasonal trawling closures in Torres Strait are adjusted to coincide with the main seasonal closure in these areas (Section 1). Metapenaeus endeavouri, endeavour prawn is often taken in association with P. esculentus (Grey et al. 1983). Although M. endeavouri is a major contributor to the commercial prawn landings of Torres Strait, very little information on its reproductive biology is available compared with P. esculentus. As the commercial catch of the Torres Strait Prawn Fishery increases (Section 2), knowledge of the reproductive biology of the penaeid prawns present in Torres Strait is required for management purposes. The reproductive biology of P. esculentus has been investigated in the Gulf of Carpentaria (Northern Prawn Fishery) (Buckworth 1985; Robertson et al. 1985; Crocos 1987b), Exmouth Gulf (Western Australia) (Penn and Caputi 1986) and the Low Isles (Queensland East Coast Fishery) (O'Connor 1979). Somers et al. (1987), investigated the reproductive activity of P. esculentus and M. endeavouri in Torres Strait. Interpretation of this study was restricted due to the three-monthly interval between sampling periods (Courtney and Dredge 1988). To enable documentation of the reproductive patterns and spawning seasons for the commercial prawn species in Torres Strait, an egg production index or a PFI (Population Fecundity Index) has been estimated. Population fecundity is the sum of the fecundities of all the females in a population (Bagenal 1973) and can be expressed in terms of an index of population fecundity (PFI) which is the number of eggs produced or potentially produced by a population. This measure has been used in combination with estimates of spawning frequency to document spawning seasons (Penn 1980). Past calculationsof a PFI for penaeid species (Penn 1980; Crocos and Kerr 1983; Crocos 1987a and 1987b; Courtney and Dredge 1988) have incorporated the proportion of female spawners in the population, their length distribution and the relationship between an individual female's fecundity with its carapace length. The PFI calculated in this study does not incorporate the proportion of female spawners in the population but uses the number of female prawns with mature ovaries per square metre of seabed swept by trawl nets as estimated from our surveys. This method is equivalent to the methods used in other reproduction studies on P. esculentus (O'Connor 1979; Buckworth 1985; Robertson et al. 1985), except these studies identified spawning peaks from the proportion of females with mature ovaries in a population (Crocos 1987a). To assess the true reproductive potential of a female prawn, the probability that it will be inseminated and therefore have fertile eggs must be determined. Crocos and Kerr (1983), Crocos (1987a and 1987b) and Courtney and Dredge (1988) studied the proportion of inseminated female penaeids but did not, however, incorporate this information into their egg production index or PFI. In this study, probability of insemination of ripe females has been incorporated into the PFI calculations. The aim of this report is to investigate the reproduction dynamics of both species to facilitate study of spawning seasonality and spawning areas for future management of the Torres Strait Fishery.

227. **Movement and Growth of Penaeus Esculentus (Haswell, 1879) Estimated from Tagging in Torres Strait**

K. Derbyshire, D. Sterling, R. Watson, A. Lisle, (1990). "Movement and Growth of Penaeus Esculentus (Haswell, 1879) Estimated from Tagging in Torres Strait," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, growth, movement, tagging, Australia, Torres Strait, brown tiger prawn

, http://www.ecomarres.com/downloads/TSChp7.pdf

Some of the most important factors in managing a fishery are: an estimate of the relative abundance of the population, the age/size composition of the population, growth rates, age at maturity, and mortality rates from fishing and natural causes (Rounsefell 1975). As juvenile prawns are found in a separate habitat from that of adults, prawn movements are also important to management. Tagging of animals for later recovery is an excellent method for estimating growth rates and migration, and for separating fishing and natural mortality rates (Gulland 1983). In some instances tagging can also be used to estimate population size (Jones 1977). Several assumptions are made concerning tagged individuals. Firstly, that the tagged individuals disperse randomly through the population to be studied before recapture, secondly that the tagged individuals are subject to the same mortality rates as untagged individuals, and thirdly that tags are not lost or overlooked when recovered (Krebs 1978). In some circumstances it is impossible not to violate one of these assumptions. Tags are known to affect speed of movement, susceptibility to predation, feeding ability and mortality (Rounsefell 1975). Despite these violations, tagging is the most reliable method for estimating growth in Penaeidae (Garcia and Le Reste 1981). Another reliable application of tagging experiments is to quantify the movement of tagged animals. A knowledge of migration patterns is an essential component in the identification of stock boundaries (Somers and Kirkwood 1984), an issue of importance for the Torres Strait Prawn Fishery which has catch sharing arrangements between two countries, Australia and Papua New Guinea. The initial objectives of this tagging programme were to describe the movements and growth of Penaeus esculentus, the brown tiger prawn.

228. **Spawning, Recruitment and Life History Studies of Penaeus Esculentus (Haswell, 1879) in Torres Strait.**

P. J. Blyth, R. Watson, D. J. Sterling, (1990). "Spawning, Recruitment and Life History Studies of Penaeus Esculentus (Haswell, 1879) in Torres Strait.," *Torres Strait prawn project: A review of research 1986-88* (Queensland Fisheries, Brisbane, Australia

shrimp, prawn, Australia, Torres Strait, brown tiger prawn, biology, recruitment, reproduction

, http://www.ecomarres.com/downloads/TSChp5.pdf

Penaeus esculentus, the brown tiger prawn, is endemic to Australian waters (Grey et al. 1983). It is found northward from southern New South Wales, through the Gulf of Carpentaria and around to Shark Bay ir Western Australia (Grey et al. 1983). Torres Strait is the most northerly extent of its distribution. Catchl P. esculentus form the main component of catches from the Torres Strait Prawn Fishery (Section 2). Except for the habitat utilized by the juvenile stage, in Torres Strait P. esculentus conforms to the penaeid life cycle as outlined by Garcia and Le Reste (1981). Juvenile P. esculentus in this region, use seagrass beds on reef-platforms as nursery areas (Section 4), and not estuaries as in other brown tiger prawn fisheries. Information on spawning and recruitment patterns of P. esculentus is essential to the implementat of management strategies such as temporal and spatial closures and effort limitation. However, there is life history information available for this species in Torres Strait. Studies on the reproductive activity of I escu!entus in the Gulf of Carpentaria (Crocos 1987; Buckworth 1985; Robertson et al. 1985) found main spawning periods from July-November. Other studies on P. esculentus in Torres Strait (Somers et al. 19: and the Low Islet region of the East Coast Prawn Fishery (O'Connor 1979) found a major spawning peril occurred in March. Information on P. esculentus recruitment patterns is confusing. Recruitment to the fishery of subadults (< 26 mm carapace length) occurred from March-May in the Exmouth Gulf (Penn and Caputi 191 and November-March in the Gulf of Carpentaria (Somers et al. 1987b). In Torres Strait, Somers et al. (1987a) found continuous recruitment to the fishery of P. esculentus from March-September followed by decrease in December. The differences in spawning and recruitment periods between the Torres Strait, Queensland East Coast and the Northern Prawn Fisheries, poses a problem for fisheries managers with regard to blanket management policies for P. esculentus. This study provides biological information on spawning and recruiment timing of P. esculentus in Torres Strait. This information can be used to formulate management strategies designed to maintain high yields in the short term, and long term productivity of the Torres Strait Prawn Fishery. .

229. **The Prawn Fishery**

R. Watson, (1986). "The Prawn Fishery," *Synopsis of the Major Torres Strait Fisheries.* (Commonwealth Dept. Primary Industry,

shrimp, prawn, statistics, catch, Torres Strait, fisheries, landings

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A description of the important commercial prawn fishery in the Torres Strait region of northern Australia. Landing and other statistics described.

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230. **Trawl Fish Composition and Harvest Estimates for the Gulf of Papua**

R. Watson, (1984). "Trawl Fish Composition and Harvest Estimates for the Gulf of Papua," *PNG Fisheries Reports* (Fisheries Research and Surveys Branch, Papua New Guinea Dept. Primary Industry, Port Moresby, Papua New Guinea

trawl, prawn, fisheries, Papua New Guinea, bycatch

, http://www.ecomarres.com/downloads/PNGTrawl.pdf

Samples of trawl fishes taken from the Gulf of Papua between June and September 1983 were dominated by weight and numbers by sciaenids, engraulids, leiognathids and trichurids. The estimated fish to prawn ratio was 8.8:1. Based on this ratio, the estimated harvest of fishes was 209 kg/hr. If this harvest was extrapolated for all trawl hours for 1982 the estimated total harvest was 11,300 - 17,200t or 1.2 - 1.9t/km2 of trawled grounds. Seasonal and area differences were noted.

231. **Changes in the Average Weight and Catch Per Unit Effort of Tunas from Papua New Guinea Waters**

R. Watson, (1984). "Changes in the Average Weight and Catch Per Unit Effort of Tunas from Papua New Guinea Waters," *PNG Fisheries Reports* (Fisheries Research and Surveys Branch, Papua New Guinea Dept. Primary Industry, Port Moresby, Papua New Guinea

tuna, fisheries, effort, landings, Papua New Guinea

, http://www.ecomarres.com/downloads/PNGTuna.pdf

Average weight of skipjack and yellowfin from the domestic pole-and-line fishery oscillated in synchrony with a period of four years and the weights of both species decreased significantly from 1970 to 1981. Although there were some significant changes in average tuna weight between years, there were no observable trends for teh Japanese longline, or Japanese and American purse-seine fisheries. The annual average weight of yellowfin from the domestic pole-and-line fishery was between 2 and 3kg, from the Japanese purse-seine 5kg, and from the Japanese longline between 23 and 26kg. The average weight of skipjack from the domestic pole-and-line and Japanese purse-seine catch was between 2 and 3 kg. The CPUE of skipjack from the Japanese pole-and-line followed that of the domestic fishery but the yellowfin CPUEs were out of phase. No long-term trends in CPUE were observed for the purse-seine or longline fisheries. The CPUE of skipjack and yellowfin from the Japanese and American purse-seine fisheries were comparable for 1982. Best CPUE fo domestic pole-and-line skipjack occured when average sizes were greatest but the converse was true for yellowfin. Generally in the various fisheries when the CPUE of skipjack increased, that of yellowfin decreased.

232. **Fisheries Research Annual Report,**

R. Watson, (1983). "Fisheries Research Annual Report,," *PNG Fisheries Research Annual Report* (Fisheries Research and Surveys Branch, Papua New Guinea Dept. Primary Industry, Port Moresby, Papua New Guinea

fisheries, Papua New Guinea, research

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During 1983 research undertaken by the Branch continued to be orientated mainly towards the development requirements of Papua New Guinea's coastal fisheries. Particularly attention has been paid to the need to develop new fishing craft and fishing methods for the artisanal fishery. Two new designs of small craft which have been constructed this year will be fully tested during 1984. Experimental fishing has concentrated on deep-line fishing and results have consistently shown that this method has potential for development in Papua New Guinea (P.N.G.). It is fully recognised that for this research to have any impact on the fishery, it must be demonstrated to the fishermen themselves and two programmes involving local fishing communities have been initiated at Port Moresby and Wewak. Fieldwork on three major projects, a shallow reef study at Kavieng, the Sepik River study and a study of estuarine fish stocks based at Baimuru were completed during 1983 and preliminary analysis has commenced and several reports have been produced. Funds allocated to Research were 30% less than in 1982 and several low priority 'tasks' were not commenced as planned. Since there has not been any major increase in staff numbers, staff shortages have been a major constraint. Research's role in the tuna, prawn and barramundi fisheries has continued to be many that of management, involving the monitoring of catch data. Research into the Torres Strait lobster stocks re-commenced in 1983 with a view to improving our understanding and management of this valuable resource.

233. **A Prediversion Analysis of the Spawning and Nursery Potential and Population of Rainbow Trout, Salmo Gaidneri, of the Neebing River, Thunder Bay, Ontario**

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Commercial prawning is a major industry in Torres Strait attracting the attention of more than I 00 vessels in a combined total annual catch of about I 000 tonnes. However, the present fishery is based on a highly mobile fleet and any change in this feature of the industry could have a dramatic effect. For this reason the Torres Strait prawn fishery needs to be looked at in conjunction with the northern prawn fishery and east coast fisheries as management practices in any one of the three areas is likely to have some effect in the other fisheries. This article presents an overall view of the Torres Strait fishery based on large-scale data collected on the fishery over the past nine years. The data shows the fishery as a whole is not being overfished but, the absence of detailed fishing information on specific areas and changes in the species composition of the catch suggest that, much more investigation remains to be carried out.

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