

Socioeconomic Aspects in Stock Assessments

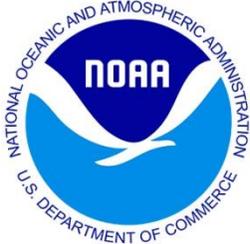
Bibliography

Erin Cheever, Librarian, NOAA Central Library

NCRL subject guide 2019-12

<https://doi.org/10.25923/hnjh-md58>

October 2019



U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
NOAA Central Library – Silver Spring, Maryland

Table of Contents

Background & Scope	3
Sources Reviewed	4
Section I: Fisher Behavior and Targeting	5
Section II: Price and Profitability.....	23
Section III: Vessel and Fleet Characteristics.....	37
Section IV: Surveys.....	44
Section V: Cost Effect on Stock Assessments.....	51
Section VI: Demographics and Community Vulnerability.....	56
Section VII: CPUE.....	62

Background & Scope

“Fisheries management initiatives directly impact the human dimensions aspects of fisheries rather than the biological characteristics of fish stocks. For example, changes in harvest control rules modify fisher behavior as well as market conditions for fish stocks (Ulrich et al. 2002). Therefore, it is important to characterize how management changes will affect fisher behavior, fishing gear and fleet compositions, market conditions, profits, as well as other socioeconomic factors that subsequently impact fish stocks. Likewise, tracking changes in fisher behavior in response to numerous drivers, such as spatial shifts in stock abundance can inform management regulations (McCay et al. 2011). Important feedback mechanisms between humans and fish stocks could be overlooked without considering socioeconomic aspects in stock assessments.” –SocioEconomic Aspects in Stock Assessments Workshop (SEASAW) Project Plan (Andrea Chan, Alan Haynie, and Patrick Lynch)

The goal of this bibliography was to locate sources that considered or incorporated socioeconomic information in fisheries stock assessments worldwide. This includes all aspects of the stock assessment process such as data collection, data processing, incorporation into stock assessment models, projected population dynamics, and integration in management plans. Sources from this bibliography will be used to write a literature review on the topic of socioeconomic factors in fisheries stock assessments.

Section I – Fisher Behavior and Targeting

This section contains relevant literature on the relationship between fisher behavior and targeting and stock assessment processes.

Section II – Price and Profitability

This section contains relevant literature on price and profitability data employed in stock assessments.

Section III – Vessel and Fleet Characteristics

This section contains relevant literature on the effect of vessel and fleet dynamics in the stock assessment process.

Section IV – Surveys

This section contains relevant literature on the use of surveys to gather data from fishers that is used in stock assessments.

Section V – Cost Effect on Stock Assessments

This section contains relevant literature on how changing costs in the fishing industry affect stock assessments.

Section VI – Demographics and Community Vulnerability

This section contains relevant literature on the socioeconomic impacts of fisheries management, the relationship between fish populations and human communities, and demographic characteristics of fishers as it relates to stock assessments.

Section VII – CPUE

This section contains relevant literature on the interaction of the catch per unit effort (CPUE) indicator and socioeconomic factors in stock assessments.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; ScienceDirect; EBSCO Academic Search Complete and Environment Complete; ProQuest Aquatic Sciences and Fisheries Abstracts; NOAA Institutional Repository; BioDiversity Heritage Library; BioOne Complete; and JSTOR.

Section I: Fisher Behavior and Targeting

Aarts, G., & Poos, J. J. (2009). Comprehensive Discard Reconstruction and Abundance Estimation Using Flexible Selectivity Functions. *ICES Journal of Marine Science*, 66(4), 763-771.
<https://doi.org/10.1093/icesjms/fsp033>

The additional mortality caused by discarding may hamper the sustainable use of marine resources, especially if it is not accounted for in stock assessment and fisheries management. Generally, long and precise time-series on age-structured landings exist, but historical discard estimates are often lacking or imprecise. The flatfish fishery in the North Sea is a mixed fishery targeting mainly sole and plaice. Owing to the gear characteristics and a minimum landing size for these species, considerable discarding occurs, especially for juvenile plaice. Discard samples collected by on-board observers are available since 1999 from a limited number of commercial fishing trips. Here, we develop a statistical catch-at-age model with flexible selectivity functions to reconstruct historical discards and estimate stock abundance. We do not rely on simple predefined selectivity ogives, but use spline smoothers to capture the unknown non-linear selectivity and discard patterns, and allow these to vary in time. The model is fitted to the age-structured landings, discards, and survey data, the most appropriate model is selected, and estimates of uncertainty are obtained.

Abbott, J. K., & Haynie, A. C. (2012). What Are We Protecting? Fisher Behavior and the Unintended Consequences of Spatial Closures as a Fishery Management Tool. *Ecological Applications*, 22(3), 762-777. <https://doi.org/10.1890/11-1319.1>

Spatial closures like marine protected areas (MPAs) are prominent tools for ecosystem-based management in fisheries. However, the adaptive behavior of fishermen, the apex predator in the ecosystem, to MPAs may upset the balance of fishing impacts across species. While ecosystem-based management (EBM) emphasizes the protection of all species in the environment, the weakest stock often dominates management attention. We use data before and after the implementation of large spatial closures in a North Pacific trawl fishery to show how closures designed for red king crab protection spurred dramatic increases in Pacific halibut bycatch due to both direct displacement effects and indirect effects from adaptations in fishermen's targeting behavior. We identify aspects of the ecological and economic context of the fishery that contributed to these surprising behaviors, noting that many multispecies fisheries are likely to share these features. Our results highlight the need either to anticipate the behavioral adaptations of fishermen across multiple species in reserve design, a form of implementation error, or to design management systems that are robust to these adaptations. Failure to do so may yield patterns of fishing effort and mortality that undermine the broader objectives of multispecies management and potentially alter ecosystems in profound ways.

Abbott, J. K., Haynie, A. C., & Reimer, M. N. (2015). Hidden Flexibility: Institutions, Incentives, and the Margins of Selectivity in Fishing. *Land Economics*, 91(1), 169-195.
<https://doi.org/10.3368/le.91.1.169>

The degree to which selectivity in fisheries is malleable to changes in incentive structures is critical for policy design. We examine data for a multispecies trawl fishery before and after a transition from management under common-pool quotas to a fishery cooperative and note a substantial shift in postcooperative catch from bycatch and toward valuable target species. We examine the margins used

to affect catch composition, finding that large-and fine-scale spatial decision making and avoidance of night-fishing were critical. We argue that the poor incentives for selectivity in many systems may obscure significant flexibility in multispecies production technologies.

Ainsworth, C. H., & Pitcher, T. J. (2005). Estimating Illegal, Unreported and Unregulated Catch in British Columbia's Marine Fisheries. *Fisheries Research*, 75(1-3), 40-55.
<https://doi.org/10.1016/j.fishres.2005.05.003>

To fully understand the impact of fishing on the marine environment, it is necessary to have an estimate of total extractions from the ecosystem. In addition to nominal fisheries landings and reported discards, which are regulated and monitored, removals will include a certain amount of illegal, unreported and unregulated catch (IUU). This amount, if considered, might profoundly affect our forecasts of stock abundance and safe removal rates. Here, we present preliminary estimates of the quantity of IUU catches over time for the British Columbia salmon and groundfish fleets. Based on influences in the history of the fisheries, and on independent estimates of misreporting, our methodology employed a Monte Carlo routine to determine missing catch with an associated error range. From the 1950s to the 1980s, we estimated that between 10,000 and 20,000 tonnes of catch went unrecorded every year in the BC salmon and groundfish fisheries. IUU catch increased throughout the 1980s, and by 1990 the amount was probably closer to 30,000 tonnes per year, equivalent to 18% of recorded landings. At present, less catch is unaccounted for thanks to tighter monitoring and enforcement: about 8000 tonnes per year, or 6.6% of landings. Values calculated here, using this subjective but transparent methodology, are intended to provide a starting point for further discussion and amendment.

Asche, F. (2009). Adjustment Cost and Supply Response in a Fishery: A Dynamic Revenue Function. *Land Economics*, 85(1), 201-215. <https://doi.org/10.3368/le.85.1.201>

In industries where firms can adjust product mix in response to price changes, the process can be delayed by adjustment costs. An example is fishermen who change fishing grounds to target different species. If adjustment costs are sufficiently large, this may hamper the fishermen's response so that regulatory tools that are not efficient in the long run are useful in the short run. Moreover, adjustment costs can influence the choice of species targeted. In this paper dynamic supply equations are specified using a revenue function approach. Different hypotheses about the dynamics of the supply equations are tested for Norwegian trawlers.

Batsleer, J., Hamon, K. G., van Overzee, H. M. J., Rijnsdorp, A. D., & Poos, J. J. (2015). High-Grading and over-Quota Discarding in Mixed Fisheries. *Reviews in Fish Biology and Fisheries*, 25(4), 715-736.
<https://doi.org/10.1007/s11160-015-9403-0>

High-grading is the decision by fishers to discard fish of low value that allows them to land more valuable fish. A literature review showed high-grading is reported in commercial and non-commercial fisheries around the world, although the number of observations is small. High-grading occurs in fisheries that are restricted to land their total catch due to management, market or physical constraints. Using the mixed flatfish fishery as a model system, a dynamic state variable model simulation showed that high-grading of certain grades occurs throughout the year when their ex-vessel price is low. High-grading increases with the degree of quota restriction, while the level of over-quota discarding is

unrelated to the quota level. The size composition of the high-graded catch differs from the landed catch. Due to the differences in the seasonal variation in size specific ex-vessel price, the effect of quota restrictions on the size composition of the discarded catch is non-linear. High-grading is difficult to detect for the fishery inspection as it occurs on-board during the short period when the catch is processed. We conclude that high-grading is under-reported in fish stocks managed by restrictive quota, undermining the quality of stock assessments and sustainable management of exploited fish stocks.

Bell, M. C., Elson, J. M., & Addison, J. T. (2005). The Effects of Spatial Targeting of Fishing Effort on the Distribution of the Norway Lobster, *Nephrops Norvegicus*, on the Farn Deeps Grounds, Northeast England. *New Zealand Journal of Marine and Freshwater Research*, 39(5), 1023-1037. <https://doi.org/10.1080/00288330.2005.9517373>

Nephrops norvegicus is an essentially sedentary species of lobster that forms the basis of valuable fisheries in the northwest Atlantic and western Mediterranean. Fishers exploiting a sedentary stock are likely to visit the most profitable (highest catch rate) areas first. Such spatial targeting of fishing effort is likely to have important consequences for stock monitoring and assessment. We used underwater television surveys of *Nephrops* burrow densities on the Farn Deeps grounds, northeast England, to describe changes in abundance and distribution between the beginning and end of a winter fishing season. Above a threshold of c. 0.6 burrows m⁻², overwinter depletion increased with burrow density, consistent with fishing effort being targeted at the highest densities. A simple simulation model showed that this pattern of mortality is an expected consequence of spatially targeted fishing behaviour. The model also predicted that there is decreased spatial variability in density after fishing. An overall decrease in variability was not evident from the Survey data, but geostatistical analysis indicated that there was "flattening" of the density profile along a north-south axis, consistent with the dominant direction of commercial trawling. We concluded that *Nephrops* fishers are able to find and exploit the highest densities of their target species. A potential consequence is that catch per unit effort (CPUE) data used to monitor trends in this stock potentially could mask declines in stock abundance. CPUE might be more effective if analysed at finer spatial scales, but this is not currently possible. In the absence of these fine scale commercial data, fishery-independent surveys (e.g., underwater television) are an important source of information on trends in stock abundance.

Branch, T. A., & Hilborn, R. (2008). Matching Catches to Quotas in a Multispecies Trawl Fishery: Targeting and Avoidance Behavior under Individual Transferable Quotas. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(7), 1435-1446. <https://doi.org/10.1139/f08-065>

Optimizing yield in multispecies fisheries is only possible when fishers have a high degree of control over the species mixture in their catches, although incentives to encourage this kind of behavior are rarely in place. One exception is the British Columbia, Canada, groundfish trawl fishery, where individual transferable quotas govern total allowable catches (TACs) for 22 species, combined with 100% observer coverage and the deduction of discard mortality from quota. Despite the number of species covered, when TACs were increased for some species and reduced for others, fishers were able to adjust the species mixture in their catches. The top 34 vessels frequented a wide range (mean 38, range 20-69) of "fishing opportunities" (repeated trawls along the same track line) containing predictable species mixtures. When TACs for rougheye (*Sebastes aleutianus*), shortraker (*Sebastes borealis*), and yelloweye rockfish (*Sebastes ruberrimus*) were sharply cut, fishers avoided fishing opportunities where these

species were more abundant. More generally, their choice of fishing opportunities depended on the expected multispecies composition, although other factors were probably also important.

Branch, T. A., Hilborn, R., Haynie, A. C., Fay, G., Flynn, L., Griffiths, J., . . . Young, M. (2006). Fleet Dynamics and Fishermen Behavior: Lessons for Fisheries Managers. *Canadian Journal of Fisheries and Aquatic Sciences*, 63(7), 1647-1668. <https://doi.org/10.1139/f06-072>

We review fleet dynamics and fishermen behavior from an economic and sociological basis in developing fisheries, in mature fisheries near full exploitation, and in senescent fisheries that are overexploited and overcapitalized. In all cases, fishing fleets behave rationally within the imposed regulatory structures. Successful, generalist fishermen who take risks often pioneer developing fisheries. At this stage, regulations and subsidies tend to encourage excessive entry and investments, creating the potential for serial depletion. In mature fisheries, regulations often restrict season length, vessel and gear types, fishing areas, and fleet size, causing or exacerbating the race for fish and excessive investment, and are typically unsuccessful except when combined with dedicated access privileges (e.g., territorial rights, individual quotas). In senescent fisheries, vessel buyback programs must account for the fishing power of individuals and their vessels. Subsidies should be avoided as they prolong the transition towards alternative employment. Fisheries managers need to create individual incentives that align fleet dynamics and fishermen behavior with the intended societal goals. These incentives can be created both through management systems like dedicated access privileges and through market forces.

Bucaram, S. J., White, J. W., Sanchirico, J. N., & Wilen, J. E. (2013). Behavior of the Galapagos Fishing Fleet and Its Consequences for the Design of Spatial Management Alternatives for the Red Spiny Lobster Fishery. *Ocean & Coastal Management*, 78, 88-100. <https://doi.org/10.1016/j.ocecoaman.2013.03.001>

The two most profitable fisheries in the Galapagos Islands, red spiny lobster (*Panulirus penicillatus*) and sea cucumber (*Isostichopus fuscus*), are facing steep declines in abundance and may be on the verge of collapse. This state of affairs has emerged in part because of command and control fisheries policies that neglected the importance of the behavior of the fishing fleet itself. Here we attempt to describe and explain the factors influencing the fishing behavior of the Galapagos red spiny lobster fishing fleet. We estimated a set of econometric models based on a random utility maximization process to forecast how changes in the immediate circumstances (economic, biological, climatic and oceanographic) impact voluntary fishing choices via the personal costs and benefits of various decisions. We focused on the factors that affect not only the decision to participate in fishing but also the decision of where to fish. We then use these models to determine the revenue elasticities for each fishing zone and to analyze the overall response of the Galapagos fleet to hypothetical closures of fishing zones. Our results provide some empirical benchmarks from which it is possible to identify in advance problems related to the spatial management of the red spiny lobster fishery and their potential solutions. For example, we found that fisherman from San Cristobal Island have a strong preference for fishing sites on Floreana Island, which is geographically closer to Santa Cruz Island. This could lead to conflicts between the San Cristobal and Santa Cruz fishing fleets if rights-based fishery management were implemented. We expect that our analysis will be valuable to policy makers when designing new types of management plans for Galapagos fisheries.

Catchpole, T. L., Feekings, J. P., Madsen, N., Palialexis, A., Vassilopoulou, V., Valeiras, J., . . . Rochet, M. J. (2014). Using Inferred Drivers of Discarding Behaviour to Evaluate Discard Mitigation Measures. *ICES Journal of Marine Science*, 71(5), 1277-1285. <https://doi.org/10.1093/icesjms/fst170>

Discards refer to the part of the catch not retained on board during commercial fishing operations, but returned to the sea. The proposed European Union Common Fisheries Policy reform, to be implemented in 2014, sets out a gradual elimination of discards by reducing unwanted catches and ensuring that all catches are landed. To develop successful discard mitigation measures, it is necessary to identify the reasons for discarding. Here, we have developed a simple model that can be applied to data from observer programmes (ObsPs) to establish the contribution of different drivers of discarding behaviour. The analysis makes inferences on the causes of discarding by partitioning discards into four categories based on the length of the fish and the associated regulatory restrictions. The drivers are defined as: fish discarded below the legal minimum landing size; fish for which there is no market and that do not have a minimum landing size; fish for which there are inconsistencies in market and sorting practices; and discards that can be attributed to fishers' responses to quota restrictions. The approach is applied to data generated from ObsPs from five European Member States. All the inferred drivers contribute to the total discard quantity. Their relative contributions vary widely across countries, areas, gears, and species.

Cisneros-Montemayor, A. M., Harper, S., & Tai, T. C. (2018). The Market and Shadow Value of Informal Fish Catch: A Framework and Application to Panama. *Natural Resources Forum*, 42(2), 83-92. <https://doi.org/10.1111/1477-8947.12143>

Fisheries catches are known to be widely underreported, and much of their value flows in informal markets. Goods and services that are not directly sold in a market also have a corresponding economic value, here termed 'shadow value', which can apply to discarded fish or those that are consumed but not sold (e.g., subsistence catches). Here, we estimate the monetary value of fisheries catches in Panama that are landed but not reported, or that are discarded at sea; this includes catches from artisanal and industrial fleets, as well as recreational and subsistence fisheries. Based on available data, we estimate that the market and shadow value of unreported catches in Panama in 2010 was around US\$92 million, equal to approximately 43% of the total reported landed value. In the case of discarded fish, the shadow value represents the potential but entirely unrealized economic benefit of landing such fish; in the case of unreported landings, unreported market value represents only the first link in the potentially sophisticated informal seafood economy. One must be careful in considering these results for policy. It is possible that, rather than seeking to capture these lost benefits, fish that are discarded or unreported should not have been caught at all, for example, if they are juveniles or of threatened species; conversely, unreported subsistence catches are crucial for food security throughout the world. These results help contextualize the scale of unreported fisheries in economic terms, and can inform subsequent policies and strategies to ensure social, ecological, and economic sustainability.

Costa, B. H. E., Batista, M. I., Goncalves, L., Erzini, K., Caselle, J. E., Cabral, H. N., & Goncalves, E. J. (2013). Fishers' Behaviour in Response to the Implementation of a Marine Protected Area. *PLOS One*, 8(6). <https://doi.org/10.1371/journal.pone.0065057>

Marine Protected Areas (MPAs) have been widely proposed as a fisheries management tool in addition to their conservation purposes. Despite this, few studies have satisfactorily assessed the dynamics of

fishers' adaptations to the loss of fishing grounds. Here we used data from before, during and after the implementation of the management plan of a temperate Atlantic multiple-use MPA to examine the factors affecting the spatial and temporal distribution of different gears used by the artisanal fishing fleet. The position of vessels and gear types were obtained by visual surveys and related to spatial features of the marine park. A hotspot analysis was conducted to identify heavily utilized patches for each fishing gear and time period. The contribution of individual vessels to each significant cluster was assessed to better understand fishers' choices. Different fisheries responded differently to the implementation of protection measures, with preferred habitats of target species driving much of the fishers' choices. Within each fishery, individual fishers showed distinct strategies with some operating in a broader area whereas others kept preferred territories. Our findings are based on reliable methods that can easily be applied in coastal multipurpose MPAs to monitor and assess fisheries and fishers responses to different management rules and protection levels. This paper is the first in-depth empirical study where fishers' choices from artisanal fisheries were analysed before, during and after the implementation of a MPA, thereby allowing a clearer understanding of the dynamics of local fisheries and providing significant lessons for marine conservation and management of coastal systems.

Cullis-Suzuki, S., McAllister, M., Baker, P., Carruthers, T., & Tate, T. J. (2012). Red Snapper Discards in the Gulf of Mexico: Fishermen's Perceptions Following the Implementation of Individual Fishing Quotas. *Marine Policy*, 36(3), 583-591. <https://doi.org/10.1016/j.marpol.2011.10.003>

In 2007, an Individual Fishing Quota (IFQ) program was introduced to the valuable red snapper (*Lutjanus campechanus*) fishery in the US Gulf of Mexico. This study assessed the current perceived scale and causes of red snapper discarding in the Gulf in recent years within the commercial reef fish fishery, according to commercial fishermen. Data were collected through interviews, which took place with fishermen in April and May 2010, and which were unexpectedly halted due to the Deepwater Horizon oil spill that occurred in late April 2010. Results suggest that for those fishermen fully participating in the IFQ program, snapper discarding has decreased since program implementation. For those not fully involved in the program (e.g., due to participation costs), discarding has likely since increased.

Curtis, R. E., & McConnell, K. E. (2004). Incorporating Information and Expectations in Fishermen's Spatial Decisions. *Marine Resource Economics*, 19(1), 131-144. <https://doi.org/10.1086/mre.19.1.42629422>

Applied economic analyses conducted on fishermen's spatial decisions have primarily used random utility models of location choice. A common characteristic of these studies is that they typically assume that fishermen have current information on catch rates at all fishing sites in the fishery, which implies a high degree of information sharing among fishermen while at sea. Using data from the Hawaii longline fishery, this paper tests this hypothesis, analyzing whether varying assumptions on information available to fishermen for basing spatial choices affects predictions regarding those decisions.

Edwards, C. T. T., & Plaganyi, E. E. (2008). Participatory Assessment of the South African Abalone Resource and Its Impact on Predicted Population Trajectories. *South African Journal of Science*, 104(5-6), 185-191. Retrieved from <http://ref.scielo.org/8jnjw3>

Illegal harvesting is a cause for concern in many of the world's fisheries. Over the last decade, the abalone resource in South Africa has come under severe fishing pressure, largely because of increased and unmitigated levels of poaching. The unquantified illegal exploitation of this resource is a major impediment to management, because understanding of abalone population dynamics is affected. Incorrect assessments of population abundance could lead to inadequate attempts by management to stem the decline. Here, population trends along the west coast of South Africa are investigated. A simple discrete-time logistic model was used to estimate parameters within a maximum likelihood statistical framework by fitting to available catch rate data. To address the problem of unknown levels of illegal catch, interview data were collected on non-commercial catch trends and the model was structured to allow this catch to be estimated during the fitting process. The results show that such a participatory approach to stock assessment can lead to an improved understanding of resource dynamics, illustrating the benefit this approach may have for management.

Eliassen, S. Q., Papadopoulou, K. N., Vassilopoulou, V., & Catchpole, T. L. (2014). Socio-Economic and Institutional Incentives Influencing Fishers' Behaviour in Relation to Fishing Practices and Discard. *ICES Journal of Marine Science*, 71(5), 1298-1307.
<https://doi.org/10.1093/icesjms/fst120>

Discard of unwanted catches are common in European fisheries, but reducing or banning this has been given high priority in the proposal for the reform of the Common Fisheries Policy. Although many technical regulations have been introduced to limit unwanted catches, there is little understanding of the underlying socio-economic and institutional incentives causing discard at the fisher level. The paper presents an approach which views discards as a result of decisions made both on deck and at earlier stages of the fishing planning and implementation process. Decisions made by fishers resulting in a more selective fishery are considered "selective behaviour". It is argued that fishing practices are institutionally embedded within three institutional spheres: "state", "market", and "community", which together with "natural conditions" create incentives and frameworks for discard and selective behaviour. A comprehensive list of factors which may influence discards and selective behaviour is developed and applied to three case studies—all trawl fisheries—in Denmark, Greece, and England. The paper discusses cross-case findings of how the identified factors may create drivers for discard. Finally, a refined list of factors is presented in a tree structure and the usefulness of the list as a tool for analysing drivers for discard and selective behaviour, in a context of developing mitigating measures, is discussed.

Gillis, D. M., Pikitch, E. K., & Peterman, R. M. (1995). Dynamic Discarding Decisions - Foraging Theory for High-Grading in a Trawl Fishery. *Behavioral Ecology*, 6(2), 146-154.
<https://doi.org/10.1093/beheco/6.2.146>

The decision by fishermen to discard or retain fish of low value to make room for more valuable fish in the hold of a boat (high-grading) is similar to diet choice problems faced by natural foragers. In our study, we apply the rationale of diet choice theory to high-grading behavior in the Oregon trawl fishery by treating fishermen as foragers who must decide how much of each net's haul to "ingest" before searching for more prey. We derive a state-dependent, temporal model of discarding behavior within a fishing trip. This optimization considers the availability of differently valued fish, trip quotas set by the regulatory agency, and the risk of premature trip termination due to loss of gear or injury. The results indicate that those parameters affect discarding behavior through their effect on the probability of exceeding the allowable catch, which we consider analogous to gut capacity. High-grading (partial prey

consumption) occurred throughout many simulated trips. The predictions were consistent with the trends in discarding observed in the Oregon trawl fleet. Behavioral models such as ours can be useful to fishery managers by providing a means to explore the potential responses of fishermen to new regulations before they are implemented.

Gillis, D. M., Rijnsdorp, A. D., & Poos, J. J. (2008). Behavioral Inferences from the Statistical Distribution of Commercial Catch: Patterns of Targeting in the Landings of the Dutch Beam Trawler Fleet. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(1), 27-37. <https://doi.org/10.1139/f07-147>

The objective identification of targeting behavior in multispecies fisheries is critical to the development and evaluation of management measures. Here, we illustrate how the statistical distribution of commercial catches can provide information on species preference that is consistent with economic data but not a simple function of price. Using the Dutch beam trawl fishery from 1998 to 2003, we show that the distribution of the log(10)-transformed catch rates of preferred species exhibit greater negative skews than less preferred species. Furthermore, subsets of the fleet employing spatially distinct strategies generate the expected patterns in the skews of their catch distributions. A simple model is presented to illustrate a behavioral mechanism for variation in skews and identify circumstances where it could apply. As a result of this analysis we propose that (i) catch distributions should be examined by species when investigating targeting behavior and (ii) changes in error structure over time can be expected in comparisons of catch statistics such as those used to create abundance indices or estimate fishing power.

Glaser, S. M., Hendrix, C. S., Franck, B., Wedig, K., & Kaufman, L. (2019). Armed Conflict and Fisheries in the Lake Victoria Basin. *Ecology and Society*, 24(1). <https://doi.org/10.5751/es-10787-240125>

Civil conflict is the most prevalent form of armed conflict in the world today, but this significant driver of food and income security has been largely missing from studies of fisheries. Fisheries conflict is an example of complex dynamics operating in social-ecological systems. We theorize and document the existence of such a feedback loop between conflict in Uganda and fisheries in Lake Victoria. Civil war in northern Uganda resulted in mass human population displacement, which corresponded in time with increases in fishing effort in Lake Victoria. Subsequent changes in catch of Nile perch, the dominant commercial fishery, sparked armed conflict in the lake itself, at Migingo Island, between Uganda and Kenya. From this case study, we draw seven main conclusions. First, these correlation-based relationships are illustrative but not conclusive and we call for further empirical investigation. Second, the couplings between conflict and fishing subsystems are spatially asymmetric: conflict effects are diffuse in their links to broad changes in the fishery, whereas fishery effects may produce more localized conflict events. Third, and most relevant to conflict scholars, the drivers of fishing effort and catch may originate in different subsystems, but their changes and effects must be analyzed in concert. Fourth, the complex and path-dependent impacts of conflicts on natural resources in general, and fisheries in particular, highlights the urgent need for targeted surveys and more mechanistic understanding. Fifth, the open access nature of fisheries in Lake Victoria may exacerbate instabilities not present in other systems. Sixth, the diffuse and context-specific effects of conflicts on fisheries means models of fisheries management (e.g., stock assessment) should not incorporate conflict as a driver at this time. Finally, countries and their stakeholders should focus on diversification in employment for short term coping mechanisms during conflict as a means of short-circuiting the conflict-fisheries feedback loop.

Gruss, A., Walter, J. F., Babcock, E. A., Forrestal, F. C., Thorson, J. T., Lauretta, M. V., & Schirripa, M. J. (2019). Evaluation of the Impacts of Different Treatments of Spatio-Temporal Variation in Catch-Per-Unit-Effort Standardization Models. *Fisheries Research*, 213, 75-93.
<https://doi.org/10.1016/j.fishres.2019.01.008>

Many stock assessments heavily rely on indices of relative abundance derived from fisheries-dependent catch-per-unit-effort (CPUE) data. Therefore, it is critical to evaluate different CPUE standardization methods under varying scenarios of data generating processes. Here, we evaluated nine CPUE standardization methods offering contrasting treatments of spatio-temporal variation, ranging from the basic generalized linear model (GLM) method not integrating a year-area interaction term to a sophisticated method using the spatio-temporal modeling platform VAST. We compared the performance of these methods against simulated data constructed to mimic the processes generating fisheries-dependent information for Atlantic blue marlin (*Makaira nigricans*), a common bycatch population in pelagic longline fisheries. Data were generated using a longline data simulator for different population trajectories (increasing, decreasing, and static). These data were further subsampled to mimic an observer program where trips rather than sets form the sampling frame, with or without a bias towards trips with low catch rates, which might occur if the presence of an observer alters fishing behavior to avoid bycatch. The spatio-temporal modeling platform VAST achieved the best performance in simulation, namely generally had one of the lowest biases, one of the lowest mean absolute errors (MAEs), and 50% confidence interval coverage closest to 50%. Generalized additive models accounting for spatial autocorrelation at a broad spatial scale (one of the lowest MAEs and one of the lowest biases) and, to a lesser extent, non-spatial delta-lognormal GLMs including a year-area interaction as a random effect (one of the lowest MAEs and one of the best confidence interval coverages) also performed adequately. The VAST method provided the most comprehensive and consistent treatment of spatio-temporal variation, in contrast with methods that simply weight predictions by large spatial areas, where it is critical, but difficult, to get the a priori spatial stratification correct before weighting. Next, we applied the CPUE standardization methods to real data collected by the National Marine Fisheries Service Pelagic Observer Program. The indices of relative abundance predicted from real observer data were relatively similar across CPUE standardization methods for the period 1998-2017 and suggested that the blue marlin population of the Atlantic declined over the period 1998-2004 and was relatively stable afterwards. As spatio-temporal variation related to environmental changes or depletion becomes increasingly necessary to consider, greater use of spatio-temporal models for standardizing fisheries-dependent CPUE data will likely be warranted.

Hanchet, S. M., Blackwell, R. G., & Dunn, A. (2005). Development and Evaluation of Catch Per Unit Effort Indices for Southern Blue Whiting (*Micromesistius Australis*) on the Campbell Island Rise, New Zealand. *ICES Journal of Marine Science*, 62(6), 1131-1138.
<https://doi.org/10.1016/j.icesjms.2005.04.01>

This paper develops standardized commercial epue indices for a highly aggregated spawning fishery in New Zealand waters, and verifies the indices using fishery-independent data. Indices were calculated for all vessels using three different measures of effort, and for vessel subsets based on processing type (surimi and dressed), and relative experience in the fishery. Trends in cpue were consistent with trends in fishery-independent acoustic surveys, age composition of the commercial catch, and recent stock assessment results. In particular, the cpue indices tracked the more than fourfold increase in abundance

from 1993 to 1996 associated with the recruitment of the strong 1991 year class, and the decline in relative abundance as this year class was fished down. Despite this being a highly aggregated spawning fishery, there was little evidence for hyperstability. There were also significant differences in fishing strategies of the fleets between periods of high and low fish abundance.

Hilborn, R. (1992). Current and Future-Trends in Fisheries Stock Assessment and Management. *South African Journal of Marine Science*, 12, 975-988. <https://doi.org/10.2989/02577619209504756>

There are currently three dominant approaches to fisheries stock assessment: analysis of catch-at-age data, simple models of biomass dynamics (often called surplus production models) that rely only on catch and some index of abundance; and analysis of length frequency data. A key characteristic of all these methods is that they rely primarily on one type of data and ignore most of what is known about the biology of the species in question and what has been learned from fisheries elsewhere. Other information is sometimes included subjectively after the stock assessment is complete. The first major trend in assessment methods is developing ways of incorporating all that is known about the biology of a species into a single unified assessment procedure. The second major development is in methods of incorporating uncertainty in stock assessment, using statistical decision theory. At present few agencies have formal methods for treating the uncertainty inherent in stock assessment, and therefore uncertainty is often ignored. A number of trends in fisheries management are reviewed, including adoption of formal harvest strategies, recognition that fisheries management is a matter of decision-making and risk-taking, and the use of Monte-Carlo evaluation of fisheries management options. Future trends in stock assessment and management will likely include more attention to the behaviour of fishermen in response to regulations, more involvement of user-groups in decision-making, much more allocation of property rights, including complete privatization of some fisheries, and demand for evaluation of cost effectiveness of research and management activities. Threats to commercial fisheries as now known are discussed, including growing allocation to recreational and aboriginal users, environmentalists and the impact of aquaculture.

Katsukawa, T., & Matsuda, H. (2003). Simulated Effects of Target Switching on Yield and Sustainability of Fish Stocks. *Fisheries Research*, 60(2-3), 515-525. [https://doi.org/10.1016/s0165-7836\(02\)00083-8](https://doi.org/10.1016/s0165-7836(02)00083-8)

Many fisheries have alternative target stocks and selectively exploit the one with the highest expected income. Although target switching is very common in practice, few attempts have thus far been made to study target switching. In this paper, we investigated the potential effects of target switching on the yield and sustainability of fish stocks by equilibrium analysis and stochastic simulation. The equilibrium analysis showed that we can increase F-extinction by switching. The stochastic simulation revealed that well-planned target switching increases yields and simultaneously decreases the risk of the stocks collapsing. Target switching decreases fishing pressure on the less-abundant stock and helps the declined stock to recover. Therefore, the minimum stock level is increased by switching. As switching keeps both stocks at productive levels, the total yield is increased by switching. Target switching is effective, especially when the catchability increases with the depletion of a stock population. Target switching depends on the availability of information on stock abundance. Thus, we examined the vulnerability of switching to stock assessment errors. If the stock assessment is very uncertain, then little or no switching is recommended. Target switching can have substantial effects on fisheries. Therefore, we must investigate the mechanisms of switching and incorporate switching into management plans.

Kristofersson, D., & Rickertsen, K. (2009). Highgrading in Quota-Regulated Fisheries: Evidence from the Icelandic Cod Fishery. *American Journal of Agricultural Economics*, 91(2), 335-346.
<https://doi.org/10.1111/j.1467-8276.2008.01189.x>

A model with nonlinear discarding costs is developed for a fishery with an individual transferable quota (ITQ) program. The model shows that limited hold capacity and ITQs provide incentives to discard fish. The model is applied to the Icelandic ITQ-regulated cod fishery to test for highgrading and to predict the discarded quantities of different grades of fish. The results indicate that vessels are involved in highgrading, but there is no evidence of quota price-induced highgrading. The predicted total discarded quantities are 4.7% and 2.7% of total landings for gillnet and longline vessels, respectively. These correspond well with official biometric estimates.

Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahevas, S., Quirijns, F., . . . Ulrich, C. (2006). Improving the Definition of Fishing Effort for Important European Fleets by Accounting for the Skipper Effect. *Canadian Journal of Fisheries and Aquatic Sciences*, 63(3), 510-533.
<https://doi.org/10.1139/f05-238>

The scope of this paper is to quantify, for a wide selection of European fisheries, fishing tactics and strategies and to evaluate the benefits of adjusting the definition of fishing effort using these elements. Fishing tactics and strategies were identified by métiers choices and a series of indices. These indices have been derived to reflect shifts in tactics (within a fishing trip) and in strategies (within a year). The Shannon-Wiener spatial diversity indices of fishing tactics (FT_SW) and strategies (YE_SW) had the greatest impact on catch rates. In particular, FT_SW was always negatively correlated to catch rates. One may anticipate that during a fishing trip, vessels with high FT_SW have been searching fish aggregations for a long time, while vessels with low FT_SW have been more efficient in finding these aggregations. The linkage between YE_SW and catch rates was of a more complex nature. Adjusting fishing effort by means of (i) the métier effect and (ii) the indices of tactics and strategies generally led to a substantial gain in the precision of the relationship between fishing mortality and fishing effort.

Parker, D., Booth, A. J., & Mann, B. Q. (2013). A Spatio-Temporal Assessment of the *Trachinotus botla* Shore-Fishery in Kwazulu-Natal, South Africa. *African Journal of Marine Science*, 35(1), 35-46.
<https://doi.org/10.2989/1814232x.2013.769908>

The shore-fishery for *Trachinotus botla* in KwaZulu-Natal appears to be in a stable state. A per-recruit assessment showed that the species is currently underexploited (spawner biomass-per-recruit = 75% of pristine levels) and that fishing mortality could theoretically be increased. The fishery was shown to display considerable spatial and temporal variability with resource abundance increasing north-easterly towards Mozambique with catch per unit effort (CPUE) peaking during summer. *Trachinotus botla* displayed random movement patterns indicative of a surf-zone resident, with 78% of the recaptures being made within 1 km of the tagging site. The movement pattern observed was not affected by fish size or time at liberty. An increasing trend in mean annual CPUE since 2002 suggests that either the resource is increasing since the promulgation of the ban on beach driving or possibly as a result of increased targeting of this species using a relatively modern technique known locally as 'dropshot'

fishing. It is likely that the beach driving ban has shifted fishing effort to accessible nodes along the coast where there is some evidence of localised overexploitation.

Pascoe, S. (1997). *Bycatch Management and the Economics of Discarding*. Food and Agriculture Organization Technical Paper No. 370. Retrieved from <http://www.fao.org/3/w6929e/w6929e00.htm>

The increase in commercial fisheries production over the last 50 years has been accompanied by an increase in the level of incidental catch and discarding of a number of species. Approximately one quarter of the marine commercial catch destined for human consumption is discarded at sea. This has raised concerns by a number of groups in society, including environmentalists, humanitarians and fishers themselves. In this paper, the economic incentives to discard fish are examined. The effects of different management policies on these incentives are also investigated. The concept of an optimal level of discarding is discussed taking into account the externalities that can be created by discarding. Finally, the effectiveness of various measures to reduce the level of discarding is reviewed. These including technical, administrative and economic measures.

Plaganyi, E. E., & Butterworth, D. S. (2010). A Spatial- and Age-Structured Assessment Model to Estimate the Impact of Illegal Fishing and Ecosystem Change on the South African Abalone *Haliotis Midiae* Resource. *African Journal of Marine Science*, 32(2), 207-236. <https://doi.org/10.2989/1814232x.2010.501561>

The management of abalone stocks worldwide is complicated by factors such as illegal fishing combined with the difficulties of assessing a sedentary (but not immobile) resource that is often patchily distributed. The South African abalone *Haliotis midae* fishery is faced with an additional problem in the form of a relatively recent movement of rock lobsters *Jasus lalandii* into much of the range of the abalone. The lobsters have heavily reduced sea urchin *Parechinus angulosus* populations, thereby indirectly negatively impacting juvenile abalone which rely on the urchins for shelter. A model is developed for abalone that is an extension of more standard age-structured assessment models because it explicitly takes spatial effects into account, incorporates the ecosystem change effect described above and estimates the magnitude of substantial illegal ('poached') catches. The model is simultaneously fitted to catch per unit effort and Fishery-Independent Abalone Survey abundance data, as well as to several years of catch-at-age (cohort-sliced from catch-at-size) data for the various components of the fishery and different spatial strata. It constitutes the first quantitative approach applied to the management of this commercially valuable resource in South Africa and has provided a basis for management advice over recent years by projecting abundance trends under alternative future catch levels.

Punt, A. E., Smith, D. C., Tuck, G. N., & Methot, R. D. (2006). Including Discard Data in Fisheries Stock Assessments: Two Case Studies from South-Eastern Australia. *Fisheries Research*, 79(3), 239-250. <https://doi.org/10.1016/j.fishres.2006.04.007>

Discarding of target species can be substantial in some fisheries. For fisheries managed using Total Allowable Catches, such as Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF), discarding of target species can occur for reasons related to the size of the fish caught, markets, and the

amount of quota held by individual quota holders. This paper illustrates how the assessments for two of the species in the SESSF, blue grenadier, *Macruronus novaezelandiae*, and the western stock of blue warehou, *Seriolella brama*, are conducted to take account of discards. Discards of blue grenadier are predominantly small fish so the assessment distinguishes between retained and discarded fish, and includes likelihood components related to the weight of the discards and the age-structure of the discards. In contrast, discards of blue warehou are due primarily to quota-related issues, so the assessment adds the discards to the catches and the catch-rate indices, and fits to total catches and catch-rates. Model outputs suggest that strong year-classes can be detected before they enter the fishery by including data on discards in assessments while ignoring such data when conducting assessments can lead to biased assessment outcomes. Several caveats related to the use of data on discards in stock assessments are outlined.

Reimer, M. N., Abbott, J. K., & Haynie, A. C. (2017). Empirical Models of Fisheries Production: Conflating Technology with Incentives? *Marine Resource Economics*, 32(2), 169-190. <https://doi.org/10.1086/690677>

Conventional empirical models of fisheries production inadequately capture the primary margins of behavior along which fishermen act, rendering them ineffective for ex ante policy evaluation. We estimate a conventional production model for a fishery undergoing a transition to rights-based management and show that ex ante production data alone arrives at misleading conclusions regarding post-rationalization production possibilities even though the technologies available to fishermen before and after rationalization were effectively unchanged. Our results emphasize the difficulty of assessing the potential impacts of a policy change on the basis of ex ante data alone. Since such data are generated under a different incentive structure than the prospective system, a purely empirical approach imposed upon a flexible functional form is likely to reflect far more about the incentives under status-quo management than the actual technological possibilities under a new policy regime.

Robinson, J., Graham, N. A. J., Cinner, J. E., Almany, G. R., & Waldie, P. (2015). Fish and Fisher Behaviour Influence the Vulnerability of Groupers (*Epinephelidae*) to Fishing at a Multispecies Spawning Aggregation Site. *Coral Reefs*, 34(2), 371-382. <https://doi.org/10.1007/s00338-014-1243-1>

Targeted fishing of spawning aggregations is a major contributor to extinction risk in numerous species of grouper (*Epinephelidae*). Marine reserves are often used to protect spawning aggregation sites, including multispecies sites shared by several species of grouper. However, marine reserves may be biologically, socioeconomically or culturally unviable in some fisheries, and alternative management actions must be explored. Implementing effective management actions that control rather than prohibit fishing requires an improved understanding of how species vary in their vulnerability to fishing gears and respond to changes in fishing effort. To estimate sources of variability in vulnerability to fishing (i.e. catchability), catch-per-unit-effort (CPUE) and other fisheries data were collected in parallel with underwater visual census-derived estimates of aggregation size at a multispecies spawning site of *Epinephelus fuscoguttatus* and *E. polyphemus*. Despite having similar abundances, *E. polyphemus* was eightfold more vulnerable to capture by hook-and-line gear, clearly outcompeting its congener for bait. Contrasting with the common assumption of a proportional relationship, the CPUE of both species was unrelated to the size of their respective aggregations. Moreover, the CPUE of each species was unrelated to hook size and depth fished. However, *E. polyphemus* CPUE declined as the density of fishing effort increased at the site, with gear saturation identified as the likely mechanism for this effect.

E. fuscoguttatus CPUE was negatively related to the size of aggregations formed by its congener, stemming from the superior competitiveness and therefore higher selectivity of the gear for *E. polyphekadion*. Our findings demonstrate that CPUE is an unreliable indicator of spawning aggregation status. The other sources of variation in CPUE that we identify have implications for gear-based management, which must be based on understanding of gear selectivity for aggregating species, and fishing effort controls, which must consider the potential for effort-dependent patterns in catchability.

Russo, T., Pulcinella, J., Parisi, A., Martinelli, M., Belardinelli, A., Santojanni, A., . . . Anderlini, L. (2015). Modelling the Strategy of Mid-Water Trawlers Targeting Small Pelagic Fish in the Adriatic Sea and Its Drivers. *Ecological Modelling*, 300, 102-113. <https://doi.org/10.1016/j.ecolmodel.2014.12.001>

Mid-water pair trawling (PTM) targeting small pelagic resources represents a key fishing activity in the Adriatic Sea. This fishery is experiencing a long period of crisis due to resource depletion and the lack of appropriate market strategies, and vessels spend most of the time searching for fishing schools. The searching strategy largely depends on the interaction between vessels: the captains of the PTM units take their decision also checking the position and the fishing status of other vessels. Understanding this strategy represents a key step towards a more effective resource management, since strategies directly determine the pattern of fishing effort. A Conditional Logit model has been devised to analyze fishermen's strategy as a non-cooperative game. This category of games is characterized by the existence of (at least) one equilibrium point - a Nash Equilibrium - in which each player plays his strategy, that is a Best Response to the strategies of the other players. This equilibrium point was estimated for the different scenarios defined by environmental (sea surface temperature and atmospheric pressure) and economic (fuel and fish prices at market) variables. Vessel Monitoring System data were used to capture fleet activity, while different datasets were collected to reconstruct environmental and economic drivers. Results indicate a good predictive power of the model, and suggest that the equilibrium strategy that guides units' behaviour is invariant with respect to environmental conditions, whereas it is largely influenced by economic factors. These latter, via strategies, may determine important consequences on the resources in terms of exploited areas and the impact of fishing activity. In particular, a low fuel price when fish price is high leads to higher values of CPUE, and then to a more efficient but also impacting fishing activity.

Salas, S., & Gaertner, D. (2004). The Behavioural Dynamics of Fishers: Management Implications. *Fish and Fisheries*, 5(2), 153-167. <https://doi.org/10.1111/j.1467-2979.2004.00146.x>

In pursuing their livelihood, fishers develop strategies when faced with changes in regulations and other fishery conditions. Changes involve each individual in a decision-making process governed by his/her own goals or constraints. Despite this reality, the complex dynamics of fishing has usually been ignored in designing management initiatives, which has contributed to management failures in many parts of the world. Fishers have generally been treated as fixed elements, with no consideration of individual attitudes based on their operating scales (geographical, ecological, social and economic) and personal goals. We review existing research on the social, economic and behavioural dynamics of fishing to provide insight into fisher behaviour and its implications for fisheries management. Emphasis is placed on fisher perception, and how fishers develop dynamic fishing tactics and strategies as an adaptive response to changes in resource abundance, environmental conditions and market or regulatory constraints. We conclude that knowledge of these dynamics is essential for effective management, and

we discuss how such information can be collected, analysed and integrated into fisheries assessment and management. Particular emphasis is placed on small-scale fisheries, but some examples from industrial fleets are provided to highlight similar issues in different types of fisheries.

Santojanni, A., Cingolani, N., Arneri, E., Kirkwood, G., Belardinelli, A., Giannetti, G., . . . Barry, C. (2005). Stock Assessment of Sardine (*Sardina pilchardus*, Walb.) in the Adriatic Sea, with an Estimate of Discards. *Scientia Marina*, 69(4), 603-617. <https://doi.org/10.3989/scimar.2005.69n4603>

Analytical stock assessment of sardine (*Sardina pilchardus*, Walb.) in the Adriatic Sea from 1975 to 1999 was performed taking into account the occurrence of discarding at sea of sardine caught by the Italian fleet. We have attempted to model the fishermen's behaviour using data collected by an observer on board fishing vessels. This enabled us to estimate the amounts of discards, which were added to the catches landed, collected by ISMAR-CNR Ancona. Discards were calculated for the period 1987-1999, as their values were negligible before 1987. Stock assessment on the entire data series from 1975-1999 was carried out by means of Virtual Population Analysis (VPA). Discarding behaviour differs among ports due to different local customs and market conditions. The quantity added to the annual total catch ranged from 900 tonnes to 4000 tonnes, corresponding to between 2% and 15% of the total corrected catch. VPAs indicated that mid-year sardine stock biomass rose steadily from 400,000 tonnes in 1975 to a peak of 950,000 tonnes in 1984. Subsequently, biomass declined steadily to the more recent values, around 300,000 tonnes. Although discarded quantities were relatively high, their influence on stock assessment was not strong because of the high level of both catch and, in particular, estimated biomass at sea.

Saul, S., & Die, D. (2016). Modeling the Decision-Making Behavior of Fishers in the Reef Fish Fishery on the West Coast of Florida. *Human Dimensions of Wildlife*, 21(6), 567-586. <https://doi.org/10.1080/10871209.2016.1198853>

When, where, and how a commercial vessel fishes determines the temporal and spatial placement of the data they are legally bound to supply to management agencies. Data provided by commercial fishing vessels are used in assessments to infer fish population abundance. Fisher decision-making may also allow fishers to dissipate the benefits of regulations and affect expected management outcomes. Decisions about participation, site choice, and trip termination were modeled for commercial fishers in the Gulf of Mexico. Vessel logbook data were used to parameterize discrete choice models for each decision. A questionnaire of vessel captains (N = 40) helped inform model structure. Results suggested that participation and site choice decisions may be nested, and are affected by expected revenue, regulations, fish price, wind speed, vessel characteristics, and fuel price. Trip termination was influenced by regulations, wind speed, and catch relative to fish hold capacity. Assessment and management implications are discussed.

Smith, M. D., & Wilen, J. E. (2003). Economic Impacts of Marine Reserves: The Importance of Spatial Behavior. *Journal of Environmental Economics and Management*, 46(2), 183-206. [https://doi.org/10.1016/s0095-0696\(03\)00024-x](https://doi.org/10.1016/s0095-0696(03)00024-x)

Marine biologists have shown virtually unqualified support for managing fisheries with marine reserves, signifying a new resource management paradigm that recognizes the importance of spatial processes in

exploited systems. Most modeling of reserves employs simplifying assumptions about the behavior of fishermen in response to spatial closures. We show that a realistic depiction of fishermen behavior dramatically alters the conclusions about reserves. We develop, estimate, and calibrate an integrated bioeconomic model of the sea urchin fishery in northern California and use it to simulate reserve policies. Our behavioral model shows how economic incentives determine both participation and location choices of fishermen. We compare simulations with behavioral response to biological modeling that presumes that effort is spatially uniform and unresponsive to economic incentives. We demonstrate that optimistic conclusions about reserves may be an artifact of simplifying assumptions that ignore economic behavior.

Somers, K. A., Pfeiffer, L., Miller, S., & Morrison, W. (2018). Using Incentives to Reduce Bycatch and Discarding: Results under the West Coast Catch Share Program. *Coastal Management*, 46(6), 619-635. <https://doi.org/10.1080/08920753.2018.1522492>

Catch share management was implemented in the bottom trawl sector of the West Coast Groundfish fishery in 2011 to address a range of issues including high bycatch and discard rates. The catch share program was designed to remove the incentives to discard through full catch accounting, tradeable quotas, increased flexibility in fishing, and penalties for catch overages. We assess the effectiveness of the program in meeting its environmental objectives by comparing discard weights, proportions, and variability from 2004-2010 with 2011-2016. We analyzed these metrics for species managed using quota, including historically overfished stocks, as well as for non-quota species caught in the fishery. Discard amounts decreased over time for all species and declined to historic lows after the implementation of the program, remaining low through 2016 with much less inter-annual variability. Mean annual discards of two highly-targeted quota species, sablefish and Dover sole, showed the greatest decreases, falling by 97 and 86%, respectively. The discard proportion of overfished quota species fell by 50% on average. The unanticipated decline in discards of non-quota species as well as the decreased variability in discard amounts for all species indicate that the incentives produced by catch share management provided additional ecosystem benefits.

Squires, D., Campbell, H., Cunningham, S., Dewees, C., Grafton, R. Q., Herrick, S. F., . . . Vestergaard, N. (1998). Individual Transferable Quotas in Multispecies Fisheries. *Marine Policy*, 22(2), 135-159. [https://doi.org/10.1016/s0308-597x\(97\)00039-0](https://doi.org/10.1016/s0308-597x(97)00039-0)

Individual transferable quotas (ITQs) are an increasingly popular form of fisheries management [1-9]. By providing fishers with a harvesting right, individual quotas have the potential to reduce excess competition and investment common in limited entry and open-access fisheries. Transferability of individual quotas fosters economic efficiency because more efficient fishers tend to harvest a greater share of the total allowable catch (TAC) and because it provides incentives for inefficient fishers to exit the fishery [10-12]. A major concern of regulators is how to implement ITQs in multispecies fisheries. The issues in multispecies fisheries also apply to multiple stock fisheries. How should a mix of species be managed where incidental catches of non-target species are common, or where the mixed species are targeted but the proportions of each species caught are uncertain? 1 How can incentives for fishers to avoid catching and discarding non-target species be increased? [14-23]. How can the problem of highgrading, where less valued fish are discarded be addressed? How should overages or catches in excess of quota holdings be regulated? How should the TAC of a mix of species be set so as to ensure the sustainability of the stocks and the profitability of fishers? Which species should receive ITQs?

Additional problems include potential changes in industry structure and community impacts because of ITQs (e.g. a few firms gain a large share of a quota and the social structures of fishing communities are substantially altered).

Thorson, J. T., Fonner, R., Haltuch, M. A., Ono, K., & Winker, H. (2017). Accounting for Spatiotemporal Variation and Fisher Targeting When Estimating Abundance from Multispecies Fishery Data. *Canadian Journal of Fisheries and Aquatic Sciences*, 74(11), 1794-1807.
<https://doi.org/10.1139/cjfas-2015-0598>

Estimating trends in abundance from fishery catch rates is one of the oldest endeavors in fisheries science. However, many jurisdictions do not analyze fishery catch rates due to concerns that these data confound changes in fishing behavior (adjustments in fishing location or gear operation) with trends in abundance. In response, we developed a spatial dynamic factor analysis (SDFA) model that decomposes covariation in multispecies catch rates into components representing spatial variation and fishing behavior. SDFA estimates spatiotemporal variation in fish density for multiple species and accounts for fisher behavior at large spatial scales (i.e., choice of fishing location) while controlling for fisher behavior at fine spatial scales (e.g., daily timing of fishing activity). We first use a multispecies simulation experiment to show that SDFA decreases bias in abundance indices relative to ignoring spatial adjustments and fishing tactics. We then present results for a case study involving petrale sole (*Eopsetta jordani*) in the California Current, for which SDFA estimates initially stable and then increasing abundance for the period 1986-2003, in accordance with fishery-independent survey and stock assessment estimates.

Ward, P., Porter, J. M., & Elscot, S. (2000). Broadbill Swordfish: Status of Established Fisheries and Lessons for Developing Fisheries. *Fish and Fisheries*, 1(4), 317-336.
<https://doi.org/10.1046/j.1467-2979.2000.00026.x>

Guidelines for the assessment and management of developing swordfish fisheries are derived through an examination of five swordfish fisheries. As they develop, swordfish fisheries may be inclined to local depletion around underwater features, such as seamounts and banks. Few nations have applied the precautionary approach in managing their developing swordfish fisheries. Without controls, swordfish fisheries expand geographically and fishing effort increases, often overshooting optimum levels. However, it is difficult to distinguish clear evidence of fishery collapse; modern longliners harvest widely distributed tuna and swordfish and they are able to relocate to distant areas or switch between target species in response to fluctuations in species abundance and price. Furthermore, the wide distribution of swordfish combined with year-round spawning and high growth rates amongst juveniles probably contribute to the apparent resilience of swordfish stocks to intensive harvesting. Over half the world's swordfish catch is taken as an incidental catch of longliners fishing for tuna. In several areas, such as the North Atlantic, catch quotas have sometimes caused tuna longline fishers to discard swordfish. Minimum size limits have also resulted in discarding of swordfish in tuna fisheries and in dedicated swordfish fisheries. In addition to weakening the effectiveness of those management measures, bycatch and discarding add to the complexities of managing swordfish fisheries and to uncertainties in assessing the stocks. Longliners that target swordfish often fish at high latitudes where interactions with marine wildlife, such as seabird, are generally more frequent than at low latitudes. Concern over incidental catches of marine wildlife and other species is becoming a driving force in the management of several swordfish fisheries. Fishery management organisations will need to implement management measures

to protect non-target species and gather reliable data and information on the situation by placing observers on boats fishing for swordfish.

Wilberg, M. J., Thorson, J. T., Linton, B. C., & Berkson, J. (2010). Incorporating Time-Varying Catchability into Population Dynamic Stock Assessment Models. *Reviews in Fisheries Science*, 18(1), 7-24.
<https://doi.org/10.1080/10641260903294647>

Catchability is an important parameter in many stock assessment models because it relates an index of abundance to stock size. We review the theory and evidence for time-varying catchability, its effects on stock assessment estimates, and methods to include time-varying catchability in stock assessments. Numerous studies provide strong evidence that time-varying catchability is common in most fisheries and many fishery-independent surveys and can be caused by anthropogenic, environmental, biological, and management processes. Trends in catchability over time can cause biased estimates of stock size and fishing mortality rates in stock assessment models that do not compensate for them. Methods that use descriptive and functional relationships have been developed to incorporate time-varying catchability in stock assessment models. We recommend that the default assumption for stock assessments should be that catchability varies over time and that multiple methods of including time-varying catchability should be applied. Additional studies are needed to determine relative performance of alternative methods and to develop methods for selecting among models.

Wilén, J. E., Smith, M. D., Lockwood, D., & Botsford, L. W. (2002). Avoiding Surprises: Incorporating Fisherman Behavior into Management Models. *Bulletin of Marine Science*, 70(2), 553-575.
Retrieved from
<https://www.ingentaconnect.com/content/umrsmas/bullmar/2002/00000070/00000002/art00012>

All fisheries-management models incorporate simplifying assumptions about ecological and oceanographic mechanisms that are fundamentally uncertain or stochastic, but exploited fisheries are also subject to equally important uncertainties associated with fisherman behavior. Fishermen make decisions ranging from long-term entry/exit decisions to daily or even hourly decisions about where and how to fish. These decisions are influenced by regulations, technology, weather, and expectations about prices, costs, and abundance. They ultimately determine the spatial and temporal pattern of mortality in an exploited fishery. Although biologists have tried to incorporate fisherman behavior into management models, much of the work is ad hoc, whereas economics has a rich tradition of both conceptual and empirical behavioral modeling. This paper is an attempt to demonstrate the potential usefulness of economics-based behavioral modeling, with data collected for biological management. A model of participation and spatial choice is constructed, and the economic model is linked to a biological model of metapopulation dynamics and used to forecast the implications of management measures that might be applied to the red sea urchin fishery in California. The results show that modeling spatial behavior strongly affects the predicted outcomes of management policies even if the policies are not spatial in character.

Section II: Price and Profitability

Batstone, C. J., & Sharp, B. M. H. (2003). Minimum Information Management Systems and ITQ Fisheries Management. *Journal of Environmental Economics and Management*, 45(2), 492-504. [https://doi.org/10.1016/s0095-0696\(02\)00015-3](https://doi.org/10.1016/s0095-0696(02)00015-3)

In 1986 New Zealand reformed its fisheries management regime with the introduction of a rights-based system of management. At the beginning of each fishing season a government agency sets an allowable commercial catch. Individual firms hold an entitlement to harvest a share of the allowable commercial catch. To date, the government agency has relied almost exclusively on the results of stock assessment research when setting the allowable harvest. Excessive reliance on biological data in fisheries management has attracted criticism. An alternative, a minimum information management system, uses information contained in quota prices as a guide to set limits on commercial harvest. This paper examines price formation in one quota market. We find evidence in the data that supports the use of quota prices to guide the setting of limits to commercial harvest. Furthermore, time-series analysis provides a basis for studying the temporal response of changes in asset prices to perturbations in the allowable harvest. The results illustrate how information summarized in quota prices can complement the findings of stock assessment research in fisheries management.

Ben-Hasan, A., Walters, C., Louton, R., Christensen, V., Sumaila, U. R., & Al-Foudari, H. (2018). Fishing-Effort Response Dynamics in Fisheries for Short-Lived Invertebrates. *Ocean & Coastal Management*, 165, 33-38. <https://doi.org/10.1016/j.ocecoaman.2018.08.019>

In complex dynamic systems like fisheries, recognizing fishing-effort responses is as critical as understanding the biology of the exploited species for making sensible management decisions. In highly seasonal fisheries, it is theoretically possible for an "interannual bionomic equilibrium" to develop under open-access, where fleet dynamics may result in balanced year-to-year harvesting due to decreasing income per time fishing as biomass declines, without endangering the sustainability of the stock. However, in some conditions, this interannual bionomic equilibrium can be pathologically low leading to overfishing and amplification of extinction risks. Here we draw three cases from short-lived and fast-growing invertebrate fisheries to illustrate two distinct effort response dynamics: (a) fishing-effort responses that lead to healthy interannual bionomic equilibrium; and (b) fishing-effort responses in which fishing remains profitable over the entire season, hence, allowing fishing fleets to maintain a high fishing-effort throughout the season. Analyzing long-term within-year catch and effort data, we found that both Gulf of Mexico shrimp and North Territory giant crab fisheries are likely currently at healthy interannual bionomic equilibria, while certain socioeconomic drivers enable the Kuwait shrimp fishery to maintain high effort through the entire shrimping season. Our findings suggest that input controls are less effective in short-lived invertebrate fisheries that exhibit fishing-effort proportional to declining stock abundance. Conversely, if not regulated, the abundance-insensitive fishing-effort response could pose biological risks and habitat destruction. Therefore, we emphasize that in common-property seasonal fisheries, fishing-effort responses be scrutinized to distinguish factors that might undermine resource sustainability.

Breen, P. A., & Kendrick, T. H. (1997). A Fisheries Management Success Story: The Gisborne, New Zealand, Fishery for Red Rock Lobsters (*Jasus edwardsii*). *Marine and Freshwater Research*, 48(8), 1103-1110. <https://doi.org/10.1071/mf97141>

After individual quotas were imposed in 1990, the fishery for *Jasus edwardsii* in the Gisborne area showed continuing declines in catch and catch rate to 1993, and the total quota could not be caught in this area. There were few legal-sized but many sublegal-sized lobsters. Pots caused mortality of sublegal lobsters through handling, pot-related Octopus predation, and thefts from commercial pots. The industry, in conjunction with recreational fishers and Maori, developed a scheme to address these problems. The aim was to increase landed value to compensate for quota reductions, and to do this by landing more lobsters in winter (when prices were higher) and landing smaller lobsters (which had a higher unit price). A shortened season was designed to reduce pot-related mortality. Part of the scheme—a proposal to reduce the minimum legal size of male lobsters—caused controversy. However, the package was evaluated with a simple model and then accepted by the Minister of Fisheries. Results were substantially increased catch rates since 1993, a successful shift to a winter fishery, and a shift in length frequencies toward larger sizes. A simple size-structured model fitted to the fishery data and used to evaluate future management options is also described.

Caddy, J. F. (1999). Fisheries Management in the Twenty-First Century: Will New Paradigms Apply? *Reviews in Fish Biology and Fisheries*, 9(1), 1-43. <https://doi.org/10.1023/a:1008829909601>

The last decade has seen growing concern at the uncertain effectiveness of most fisheries assessment and management approaches as reflected by trends in global landing statistics published by FAO. These imply full exploitation of the majority of fishery resources and a serious overcapitalization of fleets at the global level. Projected increases in demand, future prices for fisheries products, and impacts of growing world populations on the ecosystem all require an urgent search for improved management frameworks.

Cardinale, M., Dorner, H., Abella, A., Andersen, J. L., Casey, J., Doring, R., . . . Stransky, C. (2013). Rebuilding EU Fish Stocks and Fisheries, a Process under Way? *Marine Policy*, 39, 43-52. <https://doi.org/10.1016/j.marpol.2012.10.002>

As a signatory to the World Summit on Sustainable Development (WSSD), the European Union (EU) has made a commitment to maintain or restore fish stocks to levels that can produce the maximum sustainable yield (MSY), and where possible not later than 2015. So how has the EU's Common Fisheries Policy (CFP) fared in trying to achieve this objective? The development of the status of 41 commercially exploited fish stocks from the North East Atlantic, North Sea and Baltic Sea (FAO Area 27) was analysed together with the economic performance of the fleets exploiting those stocks. The analyses indicate that the exploitation status for many of the stocks has greatly improved during the last 10 years while the economic performance of the fleets over the same period has been highly variable. The main economic indicators (gross value added (GVA) and operating cash flow (OCF)) have gradually improved at a time when the general economic situation, which has a great influence on the markets, costs and purchase power, has worsened. While recognizing that much remains to be done to achieve the objective of the WSSD, the analyses indicate that actions implemented in the last decade under the CFP have led to an improvement in the status of many commercially important fish stocks and their fleets towards levels that are closer to those producing MSY.

Enomoto, K., Ishikawa, S., Hori, M., Sitha, H., Song, S. L., Thuok, N., & Kurokura, H. (2011). Data Mining and Stock Assessment of Fisheries Resources in Tonle Sap Lake, Cambodia. *Fisheries Science*, 77(5), 713-722. <https://doi.org/10.1007/s12562-011-0378-z>

The potential of catch per unit effort (CPUE) analysis based on statistics of local fisheries in Tonle Sap Lake in Cambodia was evaluated. The fishery statistics system was improved through a cooperative project conducted by the Department of Fisheries and the Mekong River Commission between 1994 and 2000, especially in the seven provinces adjacent to Tonle Sap Lake. However, the fisheries statistics were not effectively utilized for sustainable stock management. After the cooperative project, fish catch data sorted by species or species group were collected at the province level in the seven provinces. Another recent project also revealed the numbers of fishing gears that operated in the seven provinces. The CPUEs of ten species in Kampong Thom Province-including *Channa micropeltes* and *Cirrhinus* spp.-could be calculated from 1994 to 2007, because these are caught solely using bamboo fence systems or barrages. CPUE analysis clarified that stocks of high-price fishes such as *Ch. micropeltes*, *Hampala* spp., and *Pangasius* spp. have deteriorated while those of relatively low-price fishes such as *Cirrhinus* spp., *Cirrhinus microlepis*, *Cyclocheilichthys enoplos*, and *Channa striata* have increased in recent decades.

Erismán, B., Mascareñas-Osorio, I., López-Sagastegui, C., Moreno-Baez, M., Jiménez-Esquivel, V., & Aburto-Oropeza, O. (2015). A Comparison of Fishing Activities between Two Coastal Communities within a Biosphere Reserve in the Upper Gulf of California. *Fisheries Research*, 164, 254-265. <https://doi.org/10.1016/j.fishres.2014.12.011>

We engaged in collaborative research with two small-scale fishing communities inside the Upper Gulf of California Biosphere Reserve in Mexico, San Felipe (SF) and El Golfo de Santa Clara (GSC), to test how well the geographic heterogeneity of fishing activities within the reserve coincided with current regulations. We compared the two communities in terms of catch composition, fishing effort, ex-vessel prices and revenues, seasonal patterns in fishing activities in relation to the reproductive seasons of target species, and spatial patterns of fishing in relation to managed zones within the reserve. The top four species (*Cynoscion othonopterus*, *Micropogonias megalops*, *Scomberomorus concolor*, *Litopenaeus stylirostris*) in terms of relative effort, catch, and revenues were the same for both communities but overall fisheries production, effort, and revenues were higher in GSC than SF for these species. Fishing activities in GSC followed a predictable annual cycle that began with *L. stylirostris* and were followed sequentially by the harvesting of *C. othonopterus*, *M. megalops*, and *S. concolor* during their respective spawning seasons, which were associated with seasonal variations in ex-vessel prices. Conversely, catch and revenues in SF were more diversified, less dependent on those four species, less seasonal, and did not show seasonal variations in prices. Interactions between fisheries and managed zones also differed such that SF interacted mainly with the southwest portion of the vaquita (*Phocoena sinus*) refuge, whereas GSC fished over a larger area and interacted mainly with the northeast portion of the vaquita refuge and the no-take zone. Our results indicate the two communities differ markedly in their socio-economic dependence on fisheries, their spatio-temporal patterns of fishing, their use of and impacts on species, coastal ecosystems and managed areas, and how different regulations may affect livelihoods. Regional management and conservation efforts should account for these differences to ensure the protection of endangered species and to sustain ecosystem services that maintain livelihoods and healthy coastal ecosystems. This study provides further evidence of the ability of collaborative research between scientists and fishers to produce robust and fine-scale fisheries and biological information that improves the collective knowledge and management of small-scale fisheries within marine protected areas.

Fischer, S., & Wolff, M. (2006). Fisheries Assessment of *Callinectes arcuatus* (Brachyura, Portunidae) in the Gulf of Nicoya, Costa Rica. *Fisheries Research*, 77(3), 301-311. <https://doi.org/10.1016/j.fishres.2005.11.009>

The *Callinectes arcuatus* population of the Gulf of Nicoya and its current level of exploitation were investigated based on size frequency analysis of trap and trawl catches. Von Bertalanffy growth parameters ($K = 0.89$; $CW_{\infty} = 142$ mm for males) are in the range reported for other species of this family and suggest that the male size at first maturity ($CW_{mat} = 94.3$ mm) is reached in about a year. Total and natural mortality ($Z_{yr} = 2.49$; $M_{yr} = 1.32$) were derived from catch curve analysis and age at first maturity, respectively, and indicate that the stock is below full exploitation ($E = 0.47$). A yield per recruit analysis suggests that yield could be maximised, if E was increased to 0.7 under the precondition that recruitment was independent of stock size. Until this has been verified, the use of a precautionary exploitation rate ($E - 0.1$) of 0.57 is advised allowing for a 20% increase in fishing effort (from 300 traps currently being fished to around 360 traps). A maximum effort of 1600 traps, as recommended by the Instituto Costarricense de Pesca y Acuicultura (INCOPECA), is unlikely to be sustained by the population, since a decrease in the proportion of large males in the catches has already been observed over the past years under the current fishing regime. This resource is as yet only sold locally, but present catches of around 145 t seem to already cause market saturation. A greatly increased catch (at $E > 0.57$) would thus not only be detrimental to the stock but also to the market price of the resource. Future developments of the fishery should be based on a co-management approach and should involve the exploration of new market opportunities such as the "soft crab market".

Gourguet, S., Thebaud, O., Jennings, S., Little, L. R., Dichmont, C. M., Pascoe, S., . . . Doyen, L. (2016). The Cost of Co-Viability in the Australian Northern Prawn Fishery. *Environmental Modeling & Assessment*, 21(3), 371-389. <https://doi.org/10.1007/s10666-015-9486-y>

Fisheries management must address multiple, often conflicting objectives in a highly uncertain context. In particular, while the bio-economic performance of trawl fisheries is subject to high levels of biological and economic uncertainty, the impact of trawling on broader biodiversity is also a major concern for their management. The purpose of this study is to propose an analytical framework to formally assess the trade-offs associated with balancing biological, economic and non-target species conservation objectives. We use the Australian Northern Prawn Fishery (NPF), which is one of the most valuable federally managed commercial fisheries in Australia, as a case study. We develop a stochastic co-viability assessment of the fishery under multiple management objectives. Results show that, due to the variability in the interactions between the fishery and the ecosystem, current management strategies are characterized by biological and economic risks. Results highlight the trade-offs between respecting biological, economic and non-target species conservation constraints at each point in time with a high probability and maximizing the net present value of the fishery.

Grafton, R. Q. (1996). Individual Transferable Quotas: Theory and Practice. *Reviews in Fish Biology and Fisheries*, 6(1), 5-20. <https://doi.org/10.1007/bf00058517>

The paper examines the theory and practice of individual transferable quotas (ITQs) in fisheries. Using the experience of several countries, a number of ITQ programmes are examined with respect to fisher

compliance and their effect upon economic efficiency, employment, the harvesting shares of fishers, cost recovery and rent capture.

Harford, W. J., Gedamke, T., Babcock, E. A., Carcamo, R., McDonald, G., & Wilson, J. R. (2016). Management Strategy Evaluation of a Multi-Indicator Adaptive Framework for Data-Limited Fisheries Management. *Bulletin of Marine Science*, 92(4), 423-445.
<https://doi.org/10.5343/bms.2016.1025>

In data-limited fisheries, making informed management decisions based on scientific advice is challenging. Here, we evaluate a multi-indicator adaptive management framework (AMF) that allows dynamic responses to changing environmental, socioeconomic, and fishing conditions. Using stakeholder-defined goals as a foundation for specifying performance metrics, we employ management strategy evaluation (MSE) to explore the performance of the AMF relative to prescriptive alternatives that are sometimes used in data-limited situations. We conduct simulations involving the two most economically important fisheries in Belize, spiny lobster, *Panulirus argus* (Latreille, 1804), and queen conch, *Strombus gigas* (Linnaeus, 1758). Spiny lobster fishery simulations demonstrate that when relatively stable catches have historically persisted, an AMF can help to ensure that stable catches continue to persist into the foreseeable future when faced with factors such as increased entry to the fishery or environmentally induced recruitment fluctuations. The queen conch fishery simulations demonstrate that optimizing economic performance is complicated without stock status indicators and depends greatly upon the current, yet typically unknown, state of the resource. Since our indicator-based approach could not provide direct information about resource status in relation to management reference points such as maximum sustainable yield, economic objectives could not be achieved. Nevertheless, implementing the AMF served as a beneficial control against stock collapse and could function well as an interim fishery policy during which sufficient fishery data could be collected to inform population modeling and quantitative stock assessment.

Haynie, A. C., & Layton, D. F. (2010). An Expected Profit Model for Monetizing Fishing Location Choices. *Journal of Environmental Economics and Management*, 59(2), 165-176.
<https://doi.org/10.1016/j.jeem.2009.11.001>

We develop and analyze the properties of a new type of discrete choice model which jointly estimates the expected value of catch and location choice. This model implicitly monetizes location choices and can be used to predict costs and effort redistribution of creating marine protected areas or of implementing other policy changes that either increase travel costs or alter expected revenue. We illustrate our approach by considering the closing of the Steller sea lion conservation area in the United States Bering Sea to pollock fishing.

Hill, S., & Agnew, D. J. (2002). Optimal Harvest Strategies for Single-Cohort Squid Populations. *Bulletin of Marine Science*, 71(1), 371-381. Retrieved from
<https://www.ingentaconnect.com/content/umrsmas/bullmar/2002/00000071/00000001/art00028>

We explore the properties of a simple model to determine the optimal time to harvest a hypothetical squid population. Optimality criteria involve both commercial and management objectives; to maximize

profitability and ensure the survival of a minimum spawning stock. Optimal harvest times depend on natural mortality and growth rates. This relationship is modified by squid price when the commercial objective is to maximize catch value. We also consider the risk associated with mistiming of fishing events. Data from a commercially exploited squid stock, Falkland Islands *Loligo gahi*, suggest that early harvesting is often appropriate for this species.

Holland, D. S., da Silva, P. P., & Kitts, A. W. (2015). Evolution of Social Capital and Economic Performance in New England Harvest Cooperatives. *Marine Resource Economics*, 30(4), 371-392.

<https://doi.org/10.1086/682153>

In 2010 a new management system based on harvest cooperatives called "sectors" was implemented in the US Northeast Multispecies Groundfish Fishery. We hypothesize that success of individual sectors might depend on their social capital. Sector members were surveyed prior to the implementation of the policy to develop baseline measures of social capital for each sector and again after the sectors had been operating for three years. We construct indices of bonding, bridging and linking social capital, information sharing, and trust and explore how these indicators of social capital have changed since the implementation of the sector program. We also evaluate the relationship between these social capital indicators and various measures of economic performance of sectors. The result suggests that the relationship between social capital and economic performance has strengthened over time. Profitability is associated with broader community and fishery-wide connections as well as bonding social capital within sectors.

Hoshino, E., Milner-Gulland, E. J., & Hillary, R. M. (2012). Bioeconomic Adaptive Management Procedures for Short-Lived Species: A Case Study of Pacific Saury (*Cololabis saira*) and Japanese Common Squid (*Todarodes pacificus*). *Fisheries Research*, 121, 17-30.

<https://doi.org/10.1016/j.fishres.2012.01.007>

Short-lived fisheries stocks are subject to large fluctuations in abundance and respond rapidly to many factors including changes in oceanographic conditions, biological interactions and fishery exploitation. Management of such species requires a flexible, adaptive framework that responds rapidly to a changing environment, although such schemes are rarely operationalized. In this article, we develop a set of bioeconomic adaptive management schemes that respond to changes in economic conditions, stock abundance and catchability, using as case studies the fisheries targeting short-lived Japanese common squid (*Todarodes pacificus*) and Pacific saury (*Cololabis saira*). We suggest that such adaptive schemes have the potential to support the successful implementation of profit maximizing (MEY-based) harvest policies for borderline profitable fisheries targeting short-lived species.

Ives, M. C., & Scandol, J. P. (2013). Biomass: A Bio-Economic Modelling and Assessment System for Fisheries Management Strategy Evaluation. *Ecological Modelling*, 249, 42-49.

<https://doi.org/10.1016/j.ecolmodel.2012.07.006>

The primary goal of data collection on exploited fish stocks is to enable the development of credible stock assessments. Ideally, enough information will be collected to enable management strategy evaluations on the stock, providing guidance on future management decisions. In many fisheries management agencies, however, the ability to rapidly and cost-effectively build and run models to

evaluate management strategies is as much an impediment to their development as the lack of data. The BIOMAS software provides users with the ability to rapidly develop single or multi-species, length-based population dynamics models for the exploration of alternative management strategies in a Bayesian-based framework. The system is theoretically capable of incorporating any number of species, fishing fleets and spatial compartments in a single model. Further complexity is provided with the ability to implement management and environmental effects on stocks as well as the tracking of economic costs and revenue from fishing activity. However, in practice model complexity will be limited by the needs of the modelling project, by the availability of data and by the modelling project timeline. By incorporating Bayesian methods, including prior probability distributions, the BIOMAS system enables users to explore the uncertainty surrounding a limited number of parameter values and to incorporate this uncertainty into the model results. Sensitivity analyses can be run against virtually all model parameters providing insight into the key drivers for the model and likely candidates for Bayesian priors. A number of management indicators are provided for all stocks and fleets in the model including stock depletion, catch weights, age- and length-frequencies, discard mortality estimates and fleet profits - each with Bayesian-based confidence intervals. Such indicators become the primary means of comparing the effectiveness of alternative management strategies when using the system forecasting capabilities. Through the inclusion of stochastic processes, such as process error and environmental and pricing fluctuations, each management strategy can also be evaluated for its robustness to such uncertainty. The ability to reflect more of our uncertainty in modelled outcomes, which tools such as BIOMAS provide, can unfortunately come at the expense of clarity in the outcomes. This is only because these models better encompass our lack of knowledge about fishery systems. Fortunately, such modelling tools can also provide us with a clearer understanding of the main sources of this uncertainty. Furthermore, the unique design of the BIOMAS system allows users to undertake 'research strategy evaluations' in which the costs and benefits of different forms of research can be compared, allowing managers and research leaders to see more clearly the benefits of targeted research to reduce these uncertainties.

Ives, M. C., Scandol, J. P., & Greenville, J. (2013). A Bio-Economic Management Strategy Evaluation for a Multi-Species, Multi-Fleet Fishery Facing a World of Uncertainty. *Ecological Modelling*, 256, 69-84. <https://doi.org/10.1016/j.ecolmodel.2013.01.022>

A bio-economic analysis was conducted for two fisheries using a multi-species size-based meta-population model built using the BIOMAS modelling system. The model was built to represent the prawn fisheries of northern New South Wales, Australia and calibrated against 26 years of catch and effort data from this region. A number of alternative management strategies, including the use of more size selective gear and a cap on total effort, were evaluated for their impact on the sustainability of the fish stocks and the profitability of the fleets as well as their robustness to future biological, climatic and economic uncertainties. Although the differences in management strategies were blurred by the uncertainty incorporated into the model there were still some very interesting high-level insights to be gained from the analysis. The modelled prawn species appear to be much more robust to changes in management strategies and product prices than the fleet profits, suggesting the stocks are less vulnerability to such uncertainties than the fleets that harvest them. We also found larger differences in profitability from changes in product prices than from changes in management strategies, indicating that strategies to protect product prices may be of more importance to the profitability of the fisheries than changes to fishing gear or effort levels. Such results highlight the complexity of multi-species, multi-fleet fisheries and the importance of including all relevant species and fisheries in any management strategy evaluations. This complexity can however sometimes mask simple economic truths, such as the

need for strategies to maintain the market price of locally caught seafood products under the increasing pressures of international competition.

Jensen, F., & Vestergaard, N. (2003). Price Versus Quantities in Fisheries Models. *Land Economics*, 79(3), 415-425. <https://doi.org/10.2307/3147026>

This paper discusses the conditions for generalizing the analysis in Weitzman (1974) to fisheries. It is shown that it is straightforward to generalize the analysis if the cost function is direct additively separable in stock size and catches. This leads to the conclusion that the analysis holds for a schooling fishery with and without search costs, but it might not hold for a search fishery. A further result is that for a schooling fishery without search costs, where the marginal cost function is steeper than the marginal benefit function, taxes are likely to be preferred over individual transferable quotas.

Liu, O. R., Thomas, L. R., Clemence, M., Fujita, R., Kritzer, J. P., McDonald, G., & Szuwalski, C. (2016). An Evaluation of Harvest Control Methods for Fishery Management. *Reviews in Fisheries Science & Aquaculture*, 24(3), 244-263. <https://doi.org/10.1080/23308249.2016.1161002>

Fisheries managers seek to maintain sustainable fisheries production, but successful management often requires the pursuit of multiple biological, ecological, and socioeconomic objectives simultaneously. Fisheries managers must choose among a broad range of harvest control methods (HCMs) to meet management objectives. This review identifies strengths and weaknesses of eight HCMs and evaluates their ability to meet a multitude of common biological, ecological, and socioeconomic management objectives such as protecting spawning biomass, reducing bycatch, and sustaining fishers' profit. Evidence suggests that individual HCMs often fail to meet management objectives and may unintentionally create incentives to race to fish, discard catch and overcapitalize fishing operations. These limitations can be overcome by strategically combining multiple controls or incorporating rights-based and spatial management.

McGarvey, R., Matthews, J. M., Feenstra, J. E., Punt, A. E., & Linnane, A. (2016). Using Bioeconomic Modeling to Improve a Harvest Strategy for a Quota-Based Lobster Fishery. *Fisheries Research*, 183, 549-558. <https://doi.org/10.1016/j.fishres.2016.05.005>

In Australian fisheries, explicit harvest control rules are increasingly applied to achieve bioeconomic objectives. Enhancing economic return, an objective valued by both regional communities and the fishing industry, can often be achieved by increasing stock abundance, consequently supporting the second principal management objective of sustainability. A harvest strategy proposed by the fishing industry for the Southern Zone rock lobster fishery in South Australia implemented in 2011 was based on a table that, given CPUE from the preceding season, specified the following year's catch quota (total allowable commercial catch, TACC). A guiding principle in constructing the 2011 harvest control rule was to target a constant exploitation rate. Here we report on bioeconomic modeling undertaken to evaluate and improve this harvest strategy. A length-based stock assessment model was extended to forward project biological and economic time series to evaluate candidate harvest strategies. Key performance indicators were the 10-year projected discounted profit, biomass, egg production and catch stability. These simulations imply that the 2011 harvest strategy required only moderate change: (1) current or moderately lower levels of exploitation are economically optimal; (2) narrower CPUE band widths for

the TACC-vs-CPUE decision rule table enhance yearly catch stability; and (3) for depressed levels of stock abundance, exploitation rates were set to decrease linearly down to a lower limit reference point of CPUE below which the fishery is closed. A final harvest strategy incorporating these features was adopted in 2014 for yearly quota setting.

Montgomery, S. S., & Liggins, G. W. (2013). Recovery of the Eastern Rock Lobster *Sagmariasus verreauxi* Off New South Wales, Australia. *Marine Biology Research*, 9(1), 104-115.
<https://doi.org/10.1080/17451000.2012.727436>

Catch per unit effort in the fishery for eastern rock lobsters peaked in 1971-72 and then declined until 1992-93. In response to this pattern, a management package consisting of individual catch quotas, restricted entry and a legal maximum length was imposed upon the fishery. The effectiveness of these management measures to rebuild the eastern rock lobster population has been monitored annually through data collected from surveys of puerulus larvae abundance, fishery independent surveys, a compulsory logbook, observer surveys and biological studies. The total allowable commercial catch (TACC) is set annually by the TAC Committee after considering submissions from the public and industry and an annual report for the lobster fishery. The annual report prepared by government consists of an appraisal of the performance of the fishery against the objectives of the share management plan and goals of the fishery management strategy for the rock lobster fishery and includes a formal stock assessment. The trigger points behind the objectives and goals relating to the status of the stock have not been activated in the 2010-11 year. Total biomass and exploitable biomass have increased, spawner biomass has increased to now be above 25% of the pre-exploited biomass and the relative abundance of recruits (puerulus larvae) to the population is increasing. The stock is considered to be rebuilding and the resource now supports a viable fishery with an increasing share price.

O'Neill, M. F., Leigh, G. M., Wang, Y. G., Braccini, J. M., & Ives, M. C. (2014). Linking Spatial Stock Dynamics and Economics: Evaluation of Indicators and Fishery Management for the Travelling Eastern King Prawn (*Melicertus plebejus*). *ICES Journal of Marine Science*, 71(7), 1818-1834.
<https://doi.org/10.1093/icesjms/fst218>

Reduced economic circumstances have moved management goals towards higher profit, rather than maximum sustainable yields in several Australian fisheries. The eastern king prawn is one such fishery, for which we have developed new methodology for stock dynamics, calculation of model-based and data-based reference points and management strategy evaluation. The fishery is notable for the northward movement of prawns in eastern Australian waters, from the State jurisdiction of New South Wales to that of Queensland, as they grow to spawning size, so that vessels fishing in the northern deeper waters harvest more large prawns. Bioeconomic fishing data were standardized for calibrating a length-structured spatial operating model. Model simulations identified that reduced boat numbers and fishing effort could improve profitability while retaining viable fishing in each jurisdiction. Simulations also identified catch rate levels that were effective for monitoring in simple within-year effort-control rules. However, favourable performance of catch rate indicators was achieved only when a meaningful upper limit was placed on total allowed fishing effort. The methods and findings will allow improved measures for monitoring fisheries and inform decision makers on the uncertainty and assumptions affecting economic indicators.

Penn, J. W., Caputi, N., & de Lestang, S. (2015). A Review of Lobster Fishery Management: The Western Australian Fishery for *Panulirus cygnus*, a Case Study in the Development and Implementation of Input and Output-Based Management Systems. *ICES Journal of Marine Science*, 72, 22-34. <https://doi.org/10.1093/icesjms/fsv057>

Lobster stocks around the world support high-value fisheries with production currently about 260,000 tonnes annually. The largest fisheries harvest *Homarus*, *Nephrops* and *Panulirus* species with smaller production from the *Jasus*, *Palinurus* and *Scylarid* species groups. The majority of larger industrial fisheries have systems limiting fishing effort or catches, while many of the smaller fisheries remain open access and have yet to implement basic management controls. The review uses the Western Australian fishery for *Panulirus cygnus*, valued between AUS\$ 200-400 million annually with a long history of successful management, as a case study for the consideration of lobster fisheries management systems more generally. The conclusions from the review suggest that an evolutionary approach to management with biological controls as a precursor to input-based controls is necessary to allow sufficient fishery-based data to be accumulated for management decision processes to be effective. The case study experience suggests that well-defined fishing rights leading to an input-based total allowable effort system with individually transferable effort (ITE) units can provide efficient mechanisms for the reduction of latent effort, which characterises most lobster fisheries with open access or basic limited entry. Further the system has been shown to be capable of generating significant license values for fishermen while maintaining owner-operators as the dominant group in the fishery. The ITE system was also used effectively to adjust fishing to compensate for a severe environmentally-driven downturn in recruitment, but resulted in highly complex management rules. In 2010 the fishery moved seamlessly to a total allowable catch with individually transferable quotas which removed the complexity of management, further increased the catch value and reduced costs of fishing. Price/earnings (P/E) ratios have been used to track trends in license values which highlight the industry's increasing economic viability over time under both input and output based management.

Pilling, G. M., Berger, A. M., Reid, C., Harley, S. J., & Hampton, J. (2016). Candidate Biological and Economic Target Reference Points for the South Pacific Albacore Longline Fishery. *Fisheries Research*, 174, 167-178. <https://doi.org/10.1016/j.fishres.2015.09.018>

The south Pacific albacore tuna (*Thunnus alalunga*) stock is predicted to remain above the adopted limit reference point under recent increased catch levels. However, vessel catch rates are predicted fall and economic conditions worsen, which is of particular concern for those smaller-scale fleets within Pacific island countries and territories that rely on this stock for income and employment. We examine candidate target reference points that might achieve wider management objectives integrating across multiple plausible states of nature using a deterministic bio-economic model, and potential implications of those targets for the stock and fisheries through stochastic stock projections. Maximum sustainable yield (MSY), the 'default' reference point within the Western and Central Pacific Fisheries Commission, implied a relatively low stock size and more than a 1-in-3 chance of the stock falling below the limit reference point. Minimum target levels, defined by the permissible level of risk (5-20%) of falling below the limit reference point, implied larger stock sizes than at MSY, but a halving in longline catch rates that would lead to increased social and economic hardship. These results suggest that economic, rather than biological, requirements will provide the standards for an albacore target reference point. However, achieving maximum economic yield (MEY) implied severe reductions in effort, likely incompatible with objectives for employment within the local fishery sector or the level of vessel licensing revenue. Sub-optimal but improved economic performance levels examined, such as a 10% revenue margin over

economic costs, or revenues equal to the economic costs, could be obtained with less severe reductions in effort. Identifying an acceptable target reference point compatible with fishery objectives, and ways to transition from recent fishing levels to those targets, is urgently needed to ensure fleets remain viable.

Pons, M., Branch, T. A., Melnychuk, M. C., Jensen, O. P., Brodziak, J., Fromentin, J. M., . . . Hilborn, R. (2017). Effects of Biological, Economic and Management Factors on Tuna and Billfish Stock Status. *Fish and Fisheries*, 18(1), 1-21. <https://doi.org/10.1111/faf.12163>

Commercial tunas and billfishes (swordfish, marlins and sailfish) provide considerable catches and income in both developed and developing countries. These stocks vary in status from lightly exploited to rebuilding to severely depleted. Previous studies suggested that this variability could result from differences in life-history characteristics and economic incentives, but differences in exploitation histories and management measures also have a strong effect on current stock status. Although the status (bio-mass and fishing mortality rate) of major tuna and billfish stocks is well documented, the effect of these diverse factors on current stock status and the effect of management measures in rebuilding stocks have not been analysed at the global level. Here, we show that, particularly for tunas, stocks were more depleted if they had high commercial value, were long-lived species, had small pre-fishing biomass and were subject to intense fishing pressure for a long time. In addition, implementing and enforcing total allowable catches (TACs) had the strongest positive influence on rebuilding overfished tuna and billfish stocks. Other control rules such as minimum size regulations or seasonal closures were also important in reducing fishing pressure, but stocks under TAC implementations showed the fastest increase of biomass. Lessons learned from this study can be applied in managing large industrial fisheries around the world. In particular, tuna regional fisheries management organizations should consider the relative effectiveness of management measures observed in this study for rebuilding depleted large pelagic stocks.

Prellezo, R., Carmona, I., Garcia, D., Arregi, L., Ruiz, J., & Onandia, I. (2017). Bioeconomic Assessment of a Change in Fishing Gear Selectivity: The Case of a Single-Species Fleet Affected by the Landing Obligation. *Scientia Marina*, 81(3), 371-380. <https://doi.org/10.3989/scimar.04597.18A>

The European Union Common Fisheries Policy has established a discard ban, which states that fish below a reference size cannot be sold directly for human consumption. In a fishing effort-regulated fishery, the discard ban can result in extra handling, storing and landing costs. In an output-regulated fishery, this policy might also limit the effort levels as all the catches count against the quota. In both cases, this regulation can reduce the economic performance of the companies, even in single-species fisheries. A possible solution is to increase the mesh size, thus retaining fewer small individuals. To study this option, a bioeconomic simulation of a change in the gear selectivity from 100- to 120-mm minimum mesh size (MMS) was performed. The results show that the private perspective (profits) does not change. Furthermore, due to the lower retention of 120 mm MMS, the efficiency of a fishing day was reduced by 5% and 2.5%, from the point of view of capital and labour productivity, respectively. In contrast, gross revenues increased by 1.5% and crew compensation by 2%. Given a societal benefit of this change in the mesh size, this gain could be re-distributed to provide an incentive for selectivity improvements.

Punt, A. E., Smith, A. D. M., Smith, D. C., Tuck, G. N., & Klaer, N. L. (2014). Selecting Relative Abundance Proxies for B-MSY and B-MEY. *ICES Journal of Marine Science*, 71(3), 469-483.
<https://doi.org/10.1093/icesjms/fst162>

The objectives for many commercial fisheries include maximizing either yield or profit. Clearly specified management targets are a key element of effective fisheries management. Biomass targets are often specified for major commercial fisheries that are managed using quantitative stock assessments where biomass is calculated and tracked over time. B-MSY, the biomass corresponding to Maximum Sustainable Yield, is often used as a target when maximizing yield is important, while B-MEY is the biomass target to maximize profit. There are difficulties in estimating both quantities accurately, and this paper explores default proxies for each target biomass, expressed as biomass levels relative to carrying capacity, which are more easily estimated. Integration across a range of uncertainties about stock dynamics and the costs of fishing suggests that a proxy for B-MSY in the range of 3540 of carrying capacity minimizes the potential loss in yield compared with that which would arise if B-MSY was known exactly, while a proxy for B-MEY of 5060 of carrying capacity minimizes the corresponding potential loss in profit. These estimates can be refined given stock-specific information regarding productivity (particularly the parameter which defines the resilience of recruitment to changes in spawning stock size) and costs and prices. It is more difficult to find a biomass level that achieves a high expected profit than a biomass level that achieves a high expected catch, because the former is sensitive to uncertainties related to costs and prices, as well as parameters which determine productivity.

Reimer, M. N., & Haynie, A. C. (2018). Mechanisms Matter for Evaluating the Economic Impacts of Marine Reserves. *Journal of Environmental Economics and Management*, 88, 427-446.
<https://doi.org/10.1016/j.jeem.2018.01.009>

Large areas of marine and coastal environments have been protected to satisfy diverse policy goals, but there has been limited work understanding the economic impacts of such closures. While methods for establishing causal impacts are prevalent, less attention has been paid to explaining the mechanisms through which the causal relationship came to be. Understanding mechanisms is crucial for designing policies that foster the mechanisms that achieve the intended objectives of marine reserves and mitigate the mechanisms that do not. We estimate the treatment effect of a large marine reserve on the net earnings of a commercial fishery using difference-in-differences and synthetic-control designs, and decompose the treatment effect into its constituent mechanisms through structural equation modeling. We find minimal evidence that closing the marine reserve to fishing had a significant economic cost for the industry; however, several counteracting mechanisms are critical for explaining the effect and for generalizing to other settings.

Ricci Rodrigues, A., Raggi Abdallah, P., & Gasalla, M. A. (2019). Cost Structure and Financial Performance of Marine Commercial Fisheries in the South Brazil Bight. *Fisheries Research*, 210, 162-174.
<https://doi.org/10.1016/j.fishres.2018.10.017>

In Brazil, economic data on fisheries are generally scarce, and difficult to interpret with respect to costs and fishery viability, thus making it difficult to practice consistent policy and industrial decision-making. Financial performance was assessed, as were the key factors affecting the fishing costs and profitability of the major fisheries fleets that operated in three Southeast and South regions. Through an unprecedented set of field survey data from 160 fishing vessels obtained during 2013–2014, we provide

a cost-benefit comparison between different fleets and landing sites. Three generalized additive models (GAMLSS) were explored to identify major factors affecting gross profit. Fuel consumption, vessel repairs, revenue, and volume of catch were the most statistically significant factors explaining gross profit margin. For trawlers and purse-seiners, technical features such as vessel size and the number of fishing trips explained profitability, respectively, while the landing costs were significant to both types of fleet. Gross profits for trawlers also depend on ice cost and fleet type. Large pelagic fisheries showed the highest gross profit, while shrimp-trawlers, bottom-gillnetters and a purse-seining fleet showed the lowest profit, close to unviability. Indirectly, population size of target species may be influencing profitability. Labor wages increase when the financial performance of fleets improve; however, reduced yields and high operational cost levels may decrease the salaries. Specific policy advice and management strategies aiming to protect both financial performance and natural resources are highlighted, including the importance of cost-benefit analysis to help businessmen and vessel owners to identify factors that influence fleet profitability, thereby facilitating the creation of measures for increased efficiency. The approach presented may contribute to standardizing economic knowledge construction in data-poor fisheries, such as S/SE Brazil's and in other jurisdictions of Brazil or elsewhere. [ABSTRACT FROM AUTHOR]

Rugolo, L. J., Knotts, K. S., Lange, A. M., & Crecco, V. A. (1998). Stock Assessment of Chesapeake Bay Blue Crab (*Callinectes sapidus* Rathbun). *Journal of Shellfish Research*, 17(2), 493-517. Retrieved from <https://www.sciencebase.gov/catalog/item/5053f2ade4b097cd4fcf7a4d>

This stock assessment stemmed from concerns about declines in Chesapeake Bay blue crab commercial yield, survey abundance indices, and economic performance in the 1990s. Blue crab vital rates and life-history characteristics were described. A risk-averse approach was adopted for parameter estimation. Extant (50 y) fisheries-independent and dependent data were compiled. Current spawning stock biomass was at moderate levels, as compared to historical maxima; total stock biomass was at long-term average levels since 1956. Juvenile recruitment has been variable since the 1950s. The stock is in long-term dynamic equilibrium, demonstrating variable abundance as expected in a strongly r-selected species. No evidence of a persistent stock decline was found. The decade of the 1980s was a period of above average abundance; the population modulated to average levels thereafter. Maryland commercial catch per unit effort (CPUE) has remained fairly stable from 1982 to 1995. Baywide yield varied without trend since 1945, cycling around the long-term mean with peaks in 1950, 1966, 1981, and 1993 and troughs in the mid-1950s and late 1970s to early 1980s. Baywide data since 19-15 demonstrated a fivefold increase in directed effort (f) and an exponential decline in CPUE: rapidly from 1947 to 1967, and without trend since 1970. The stock has supported maximum sustainable yield (MSY) = 37-38.5 x 10⁶ kg since 1935 with no observed change in the ability of the stock to replace itself or to provide historical average yield. We judged the stock to be moderately to fully exploited at average levels of abundance. Stock-recruitment (S-R) analysis revealed weak relationships. Density-independent effects accounted for little of the variability in the S-R model. Exploitation rates for 1956 to 1996 ranged from 30-40% for peeler/soft crabs and 40-55% for hard crabs. Fishing mortality (F) ranged largely between 0.8-1.0 (F < 1.20) since 1956 within +/- 20% of the long-term mean; fully recruited F in 1996 was 0.87. Current F was below the threshold reference level of F-10% = 1.21, where F-REP = 1.17. Yield per recruit (YPR) modeling estimated F-0.1 = 0.36 and F-MAX = 0.64. The stock is strictly growth overfished with a 26% reduction in F-10% required to maximize (+2% gain) YPR. Longevity was established at 8 y. Tagging studies showed that blue crabs live considerably longer than current convention (3 y). A life-table model reconciled the apparent disparity between this convention and the life-history parameters used in the assessment. At current total mortality (Z) approximate to 1.3, the

mean age of the observed stock would be 1.5 y (153 mm CW [carapace width]; 97.3% of all individuals would be greater than or equal to 3 y of age. The dramatic rise in f since 1945 with the accompanying decline in CPUE was not associated with an increase in F . Catchability (q) has varied with f from 1956 to 1995 as a result of gear saturation. Moderate reductions in f would not result in a proportional reduction in F because of nonconstant q . The blue crab fishery is severely overcapitalized in terms of total effort. As a result of gear saturation, marginal decreases in fishing effort would not realize proportional gains in CPUE, %MSP, or YPR. Substantial economic displacement would be required to maximize YPR. Increases in %MSP and YPR could be realized through increased size limits and regulating the taking of mature female crabs, without the displacement costs associated with effort reductions alone. We recommend a risk-averse management strategy: maintain current F below $F-10\%$. Management should be particularly averse to increases in effort that would exacerbate current economic inefficiencies, or to increases in gear efficiency. The latter concern acknowledges the delicate interplay between F and f in the fishery. Management should be proactive: stabilize and enhance the economic viability of the fishery and provide protection for the stock through maintenance of greater than or equal to 10% maximum spawning potential (MSP). It should consider adopting strategies which increase YPR (e.g., size limit measures on both sexes) and spawning potential (e.g., limit directed fisheries on mature female crabs).

Sethi, S. A. (2010). Risk Management for Fisheries. *Fish and Fisheries*, 11(4), 341-365.
<https://doi.org/10.1111/j.1467-2979.2010.00363.x>

Risk management methods provide means to address increasing complexity for successful fisheries management by systematically identifying and coping with risk. The objective of this study is to summarize risk management practices in use in fisheries and to present strategies that are not currently used but may be applicable. Available tools originate from a variety of disciplines and are as diverse as the risks they address, including algorithms to aid in making decisions with multiple stakeholders, reserves to buffer against economic or biological surprises, and insurance instruments to help fishermen cope with economic variability. Techniques are organized in a two-stage framework. In the first stage, risks are identified and analysed. Strategies presented in this category focus on decision analysis, including multicriteria decision-making tools, and the related concept of risk assessment. Then in the treatment stage, identified risks can be transferred, avoided, or retained using tools such as the Precautionary Approach, portfolio management, financial contracts to manage price risk and horizontal integration. Published fishery applications are reviewed, and some empirical examples of risks and risk management using US fisheries data are presented.

Simons, S. L., Ralf, D., & Axel, L. (2015). Combining Area Closures with Catch Regulations in Fisheries with Spatio-Temporal Variation: Bio-Economic Implications for the North Sea Saithe Fishery. *Marine Policy*, 51, 281-292. <https://doi.org/10.1016/j.marpol.2014.08.017>

Although there exists an EU-Norway long-term management plan for North Sea saithe, including a catch regulation, the spawning stock biomass has declined in the last few years, recruitment has been below average since 2006 and growth rates are low. Moreover, catch rates used as a proxy of stock abundance in stock assessment, are believed to decline much more slowly than the actual stock abundance. Thus, a quota-based system may not be sufficient to sustain the stock. A bio-economic simulation and optimisation model was used to explore how various area closures in combination with the quota-system affect levels of by-catch, net profit of individual fleet segments from different ports, and stock

development in that fishery. Tested area closures differed in duration, size and location relative to major ports and to seasonal movement patterns of species. These closures were tested under variable recruitment. Area closures that were covering the seasonal migration route of saithe revealed almost two times greater increases in spawning stock biomass than closures that were not covering the migration route. Even area closures where a high dispersal rate of individuals was assumed resulted in increased spawning stock biomass of saithe. Benefits of the tested area closures were distributed heterogeneously among individual fleet segments. Increases of saithe stock size were offset by increases in cod by-catch. The location of an area closure relative to the home port of fleet segments decided if steaming costs increased and catches decreased.

Woods, P. J., Holland, D. S., Marteinsdottir, G., & Punt, A. E. (2015). How a Catch - Quota Balancing System Can Go Wrong: An Evaluation of the Species Quota Transformation Provisions in the Icelandic Multispecies Demersal Fishery. *ICES Journal of Marine Science*, 72(5), 1257-1277. <https://doi.org/10.1093/icesjms/fsv001>

Implementation of single-species catch limits in multispecies individual quota systems is problematic because it may incentivize discarding behaviour when quotas for some species limit catch of jointly caught species. Since discarding may reduce economic benefits and bias stock assessments, mechanisms that reduce incentives to discard can be beneficial. However, these mechanisms may be detrimental in the long term if they also pose a risk of stock depletion, which can occur if they enable catch to persistently exceed the total allowable catch (TAC). This study uses a bioeconomic model to analyse potential negative consequences of species quota transformation provisions, using the Icelandic individual transferable quota system as a case study. These provisions allow quota of one species to be transformed into quota of another species at specified rates related to relative market value. The system reduces the degree that the TAC of any particular species constrains catch of other species. However, it also allows catches of some species to exceed TACs, possibly leading to stock depletion. We explore how these provisions may affect long-term sustainability of individual species and profitability of the fishery as a whole. We focus on the extreme case of perfect targeting (i.e. full control of catch composition) to increase intuition on the potential for adverse effects of this system. Various combinations of species profitability are examined to determine attributes of species that lead to greater vulnerability, as well as interactions in species utilization. Consequences of changing harvest control rules are explored, and information needed to monitor for unintended consequences of such a system in practice are discussed. Although the species transformation system is designed to increase economic efficiency, our results show that it could lead to depletion in some cases, and may make it difficult to achieve optimal management goals.

Section III: Vessel and Fleet Characteristics

Bastardie, F., Vinther, M., Nielsen, J. R., Ulrich, C., & Paulsen, M. S. (2010). Stock-Based Vs. Fleet-Based Evaluation of the Multi-Annual Management Plan for the Cod Stocks in the Baltic Sea. *Fisheries Research*, 101(3), 188-202. <https://doi.org/10.1016/j.fishres.2009.10.009>

This study evaluated the EU 2008 multi-annual plan for Baltic cod stock recovery. The plan combines harvest control rules that set TACs with reductions in direct effort (E) and fishing mortality (F). Performance and robustness of the plan are tested with a management strategy evaluation model (MSE). Stochastic simulations are carried out under different scenarios of recruitment and sources of uncertainties. Under the different magnitudes of errors investigated, the plan in its current design is likely to reach precautionary targets for the Eastern and the Western Baltic cod stocks by 2015. It is, however, more sensitive to implementation errors (e.g. catch misreporting) than to observation errors (e.g. data collection) when the (i) current settings of the ICES single-stock assessment model are maintained, (ii) intended fishing effort reduction is fully complied with, and (iii) biological parameters are assumed constant. For the Eastern Baltic stock, additional sources of uncertainties from fishery adaptation to the plan are tested using a fleet-based and spatially explicit version of the model which leads to higher reductions in F and no significant change in management robustness. The relative difference between both approaches is mainly due to differences in exploitation patterns in catching the same amount of fish. The effort control is demonstrated to be more efficient when supplemented with a TAC and avoids un-intended effects from fishery responses, e.g. spatial effort reallocation. Medium term economic evaluation of fishery performance shows an initial reduction in profit with effort and TAC reductions, but profit is always positive.

Chen, C. S., & Chiu, T. S. (2009). Standardising the CPUE for the *Illex argentinus* Fishery in the Southwest Atlantic. *Fisheries Science*, 75(2), 265-272. <https://doi.org/10.1007/s12562-008-0037-1>

The catch per unit effort (CPUE) is a widely used index for assessing the abundance of exploited populations in fishery management. To obtain appropriate CPUE values, it is essential to standardise catch-effort data from fisheries. This task is particularly important for squid fisheries because squid generally have a short life-span and are vulnerable to environmental variability, and thus effective fishery management should take such factors into account. In this study, we analysed unit catches of paired vessels operating under similar fishing conditions to calculate their relative fishing power (RFP) in order to standardise the CPUE of the Taiwanese fleet jigging for *Illex argentinus* in the Southwest Atlantic. To evaluate the appropriateness of the method, we used a logbook dataset covering eleven years (1993-2003), in which 93.5% of the total catch during the period was included. The results indicate that 98.7% of the fishing effort can be standardised according to the estimated RFP. Compared to nominal CPUE, the standardised CPUE values projected an explainable temporal pattern, indicating an increasing trend in abundance from 1995 to 1999 and a subsequent sharp plunge from 1999 to 2003. However, the RFP was not related to apparent physical factors of the vessel, such as gross tonnage or vessel length. Our evaluations suggest that the RFP method is appropriate for standardising the CPUE, so that it can serve as an abundance index that reflects the annual recruitment size of the squid fishery, because the quality of the method can potentially take possible affecting factors into account in order to satisfy the general assumptions of standardisation criteria. However, the effects of varying the settings of parameters should be carefully examined prior to applying this standardisation method to other squid fisheries.

Garcia, D., Prellezo, R., Sampedro, P., Da-Rocha, J. M., Castro, J., Cervino, S., . . . Gutierrez, M. J. (2017). Bioeconomic Multistock Reference Points as a Tool for Overcoming the Drawbacks of the Landing Obligation. *ICES Journal of Marine Science*, 74(2), 511-524. <https://doi.org/10.1093/icesjms/fsw030>

The landing obligation policy was one of the major innovations introduced in the last Common Fisheries Policy reform in Europe. It is foreseen that the policy will affect the use of fishing opportunities and hence the economic performance of the fleets. The problem with fishing opportunities could be solved if single-stock total allowable catches (TACs) could be achieved simultaneously for all the stocks. In this study, we evaluate the economic impact of the landing obligation policy on the Spanish demersal fleet operating in the Iberian Sea region. To generate TAC advice, we used two sets of maximum sustainable yield (MSY) reference points, the single-stock MSY reference points defined by ICES and a set of multistock reference points calculated simultaneously using a bioeconomic optimization model. We found that the impact of the landing obligation is time and fleet dependent and highly influenced by assumptions about fleet dynamics. At fishery level, multistock reference points mitigate the decrease in the net present value generated by the implementation of the landing obligation. However at fleet level, the effect depends on the fleet itself and the period. To ensure the optimum use of fishing opportunities, the landing obligation should be accompanied by a management system that guarantees consistency between single-stock TACs. In this regard, multistock reference points represent an improvement over those currently in use. However, further investigation is necessary to enhance performance both at fleet level and in the long term.

Gascuel, D., Merino, G., Doring, R., Druon, J. N., Goti, L., Guenette, S., . . . Mackinson, S. (2012). Towards the Implementation of an Integrated Ecosystem Fleet-Based Management of European Fisheries. *Marine Policy*, 36(5), 1022-1032. <https://doi.org/10.1016/j.marpol.2012.02.008>

Using the Celtic Sea and the North Sea as case studies, the fleet-based approach is shown to be the pathway to implement an effective ecosystem approach to fisheries management (EAFM) in European seas. First, a diagnostic on the health of each ecosystem is proposed based on the reconstruction of long time-series of catch, the analysis of mean indicators or stocks trajectories derived from ICES stock assessment results, and the analysis of ecosystem indicators. Then, a Fleet-based synthesis is presented using indicators of both the ecological impact and the economic performances of the major fleets operating within each ecosystem. In particular, assessment diagrams show whether each fleet segment, on average, sustainably exploits the stocks. Although results are preliminary due to the poor quality of available data, the analysis shows that simple indicators can be estimated and clearly highlight contrasts between fleet segments. Such an approach contributes to the evolution from a stock-based to a fleet-based management, which reflects the ecological, economical and social pillars of the sustainable development of fisheries.

Gillis, D. M. (2003). Ideal Free Distributions in Fleet Dynamics: A Behavioral Perspective on Vessel Movement in Fisheries Analysis. *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, 81(2), 177-187. <https://doi.org/10.1139/z02-240>

Since fleet dynamics was defined in the 1980s there has been increasing interest in the role played by vessel behavior in the exploitation of aquatic resources. The ideal free distribution (IFD), from behavioral ecology, has proved useful for examining the relationship between vessel and resource distributions in commercial fisheries. When making inferences based upon the IFD it is critical to examine its underlying assumptions, particularly the form of competition between fishing vessels. When present, an IFD can decouple the relationship between local catch rates and abundance, obscuring declines in smaller or weaker fish stocks. As an alternative, probabilistic methods have also been successfully applied to the study of vessel behavior. However, parsimonious behavioral models like the IFD will often be preferable

because (i) they can be examined using the data typically available from commercial fisheries, (ii) they require fewer data than probabilistic models, and (iii) they are easily incorporated into more complex management models as the fishing component. Where deviations from the IFD occur they can provide insights into the relationship between regulations, environment, and vessel activities that will improve our interpretation of the data generated by commercial fisheries.

Gourguet, S., Thebaud, O., Dichmont, C., Jennings, S., Little, L. R., Pascoe, S., . . . Doyen, L. (2014). Risk Versus Economic Performance in a Mixed Fishery. *Ecological Economics*, 99, 110-120. <https://doi.org/10.1016/j.ecolecon.2014.01.013>

Balancing bio-economic risks and high profit expectations is often a major concern in fisheries management. We examine this trade-off in the context of the Australian Northern Prawn Fishery (NPF). The fishery derives its revenue from different prawn species with different dynamics and recruitment processes. A multi-species bio-economic and stochastic model is used to examine the trade-offs between mean profitability of the fishery and its variance, under a range of economic scenarios, fishing capacities and distributions of fishing effort across the various sub-fisheries that comprise the NPF. Simulation results show that the current fishing strategy diversifying catch across sub-components of the fishery entails a compromise between expected performance and risk. Furthermore, given the current economic conditions, increases in fleet size would improve the expected economic performance of the fishery, but at the cost of increased variability of this performance.

Kaplan, I. C., Holland, D. S., & Fulton, E. A. (2014). Finding the Accelerator and Brake in an Individual Quota Fishery: Linking Ecology, Economics, and Fleet Dynamics of US West Coast Trawl Fisheries. *ICES Journal of Marine Science*, 71(2), 308-319. <https://doi.org/10.1093/icesjms/fst114>

In 2011, the Pacific Fisheries Management Council implemented an individual transferrable quota (ITQ) system for the US West Coast groundfish trawl fleet. Under the ITQ system, each vessel now receives transferrable annual allocations of quota for 29 groundfish species, including target and bycatch species. Here we develop an ecosystem and fleet dynamics model to identify which components of an ITQ system are likely to drive responses in effort, target species catch, bycatch, and overall profitability. In the absence of penalties for discarding over-quota fish, ITQs lead to large increases in fishing effort and bycatch. The penalties fishermen expect for exceeding quota have the largest effect on fleet behaviour, capping effort and total bycatch. Quota prices for target or bycatch species have lesser impacts on fishing dynamics, even up to bycatch quota prices of \$50 kg⁻¹. Ports that overlap less with bycatch species can increase effort under individual quotas, while other ports decrease effort. Relative to a prior management system, ITQs with penalties for exceeding quotas lead to increased target species landings and lower bycatch, but with strong variation among species. The model illustrates how alternative fishery management policies affect profitability, sustainability and the ecosystem.

Mikkonen, S., Rahikainen, M., Virtanen, J., Lehtonen, R., Kuikka, S., & Ahvonen, A. (2008). A Linear Mixed Model with Temporal Covariance Structures in Modelling Catch Per Unit Effort of Baltic Herring. *ICES Journal of Marine Science*, 65(9), 1645-1654. <https://doi.org/10.1093/icesjms/fsn135>

Changes in the structure and attributes of a fleet over time will break down the proportionality of catch per unit effort (cpue) and stock biomass. Moreover, logbook data from commercial fisheries are hierarchical and autocorrelated. Such features not only complicate the analysis of cpue data but also seriously limit the application of a generalized linear model approach, which nevertheless is applied commonly. We demonstrate a linear mixed model application for a large hierarchical dataset containing autocorrelated observations. In the analysis, the key idea is to explore the properties of the error term of the model. We modified the residual covariance matrix, allowing the introduction of assumed fisher behaviour, influencing the catch rate. Fisher behaviour consists of accumulated knowledge and learning processes from their earlier area- and time-specific catch rates. Also, we investigated the effects of vesselspecific parameters by introducing random intercepts and slopes in the model. A model with the autoregressive moving average residual covariance matrix structure was superior over the block-diagonal and autoregressive (AR1) structure for the data, having a time-dependent correlation among trawl hauls. The results address the benefits of statistically advanced methods in obtaining precise and unbiased estimates from cpue data, to be used further in stock assessment. Fisheries agencies are encouraged to monitor the relevant vessel and gear attributes, including engine power and gear size, and the deployment practices of the gear.

Pascoe, S., Coglan, L., Punt, A. E., & Dichmont, C. M. (2012). Impacts of Vessel Capacity Reduction Programmes on Efficiency in Fisheries: The Case of Australia's Multispecies Northern Prawn Fishery. *Journal of Agricultural Economics*, 63(2), 425-443. <https://doi.org/10.1111/j.1477-9552.2011.00333.x>

Capacity reduction programmes, in the form of buybacks or decommissioning, have had relatively widespread application in fisheries in the US, Europe and Australia. A common criticism of such programmes is that they remove the least efficient vessels first, resulting in an increase in average efficiency of the remaining fleet, which tends to increase the effective fishing power of the remaining fleet. In this paper, the effects of a buyback programme on average technical efficiency in Australia's Northern Prawn Fishery are examined using a multi-output production function approach with an explicit inefficiency model. As expected, the results indicate that average efficiency of the remaining vessels was generally greater than that of the removed vessels. Further, there was some evidence of an increase in average scale efficiency in the fleet as the remaining vessels were closer, on average, to the optimal scale. Key factors affecting technical efficiency included company structure and the number of vessels fishing. In regard to fleet size, our model suggests positive externalities associated with more boats fishing at any point in time (due to information sharing and reduced search costs), but also negative externalities due to crowding, with the latter effect dominating the former. Hence, the buyback resulted in a net increase in the individual efficiency of the remaining vessels due to reduced crowding, as well as raising average efficiency through removal of less efficient vessels.

Richter, A., Eikeset, A. M., van Soest, D., Diekert, F. K., & Stenseth, N. C. (2018). Optimal Management under Institutional Constraints: Determining a Total Allowable Catch for Different Fleet Segments in the Northeast Arctic Cod Fishery. *Environmental and Resource Economics*, 69(4), 811-835. <https://doi.org/10.1007/s10640-016-0106-3>

Many real world fisheries have an individual vessel quota system with restrictions on transferability of quota or entrance of new vessels into the fishery. While the standard economic reasoning is that these institutional constraints lead to welfare losses, the size of those losses and optimal second-best policies are usually unknown. We develop a dynamic bioeconomic model, in which a scientific body provides an optimal TAC given restrictions on (i) transferability between vessel segments and (ii) entrance of new vessels. Further, we also quantify welfare losses arising from not maximizing economic welfare, but physical yield--which is actually the case in many fisheries. We apply the model to the Northeast Arctic cod fishery, and estimate not only the cost and harvesting functions of the various vessel types, but also the parameters of the biological model as well as those of the demand function. This allows us to determine optimal second-best policies and quantify corresponding welfare effects for our case study fishery.

Sharma, R., Pons, M., Martin, S., Kell, L., Walter, J., Lauretta, M., & Schirripa, M. (2018). Factors Related to the Decline and Rebuilding of Billfish Stocks in the Atlantic and Indian Oceans. *ICES Journal of Marine Science*, 75(2), 880-891. <https://doi.org/10.1093/icesjms/fsx081>

The article examines factors related to the decline and rebuilding of billfish stocks in the Atlantic and Indian oceans. Longline effort has declined over the last 10-15 years in both oceans. This decline in fishing pressure has led to the recovery of some stocks, but some species that are caught incidentally in industrial longline fisheries remain overexploited. Using a simple moving average technique on fishing mortality trajectories, we estimated a threshold effort size of 240 million hooks for the Atlantic Ocean and 364 million hooks for the Indian Ocean where stocks start experiencing overfishing. In addition, we highlight differences in the economic characteristics of the major fleets catching billfish in the two oceans and discuss how this may be associated with differences in management, enforcement, and stock rebuilding.

Thorson, J. T., & Ward, E. J. (2014). Accounting for Vessel Effects When Standardizing Catch Rates from Cooperative Surveys. *Fisheries Research*, 155, 168-176. <https://doi.org/10.1016/j.fishres.2014.02.036>

Interpretation of fishery-dependent and independent-survey data requires accounting for changes in the proportion of local individuals that are caught by fishing gear ("catchability"). Catchability may be influenced by measured characteristics of fishing gear, and even standardized fishing techniques may experience changing catchability over time due to changes in fishing vessel characteristics and personnel. The importance of vessel power has long been recognized in the analysis of fishery dependent catch per unit effort data, but less-studied in the analysis of fishery independent data collected by research vessel surveys. Here we demonstrate how differences in catchability among vessels ("vessel effects"), as well as random variation in vessel-specific catchability over time ("vessel-year effects") can be incorporated into generalized linear mixed models through their treatment as random effects. We apply these methods to data for 28 groundfish species caught in a standardized survey using contracted fishery vessels and personnel in the Northeast Pacific. Model selection shows that vessel, vessel-year, and both effects simultaneously are supported by available data for at least a few species. However, vessel-year effects generally have a larger effect on catch rates than vessel-effects and hence abundance indices estimated using both vessel- and vessel-year effects are generally similar to estimates when using just vessel-year effects. Additionally, models indicate little support for the hypothesis that characteristics such as length and displacement of the contracted vessels used in

this survey have a substantial impact on catch rates. Finally, inclusion of vessel- or vessel-year effects generally results in wider estimates of credible intervals for resulting indices of abundance. This increased credible interval width is consistent with statistical theory, because vessel effects will result in non-independence of different sampling occasions, thus decreasing effective sample sizes. For this reason, we advocate that future analyses include vessel- and/or vessel-year effects when standardizing survey data from cooperative research programs.

van Putten, I. E., Kulmala, S., Thebaud, O., Dowling, N., Hamon, K. G., Hutton, T., & Pascoe, S. (2012). Theories and Behavioural Drivers Underlying Fleet Dynamics Models. *Fish and Fisheries*, 13(2), 216-235. <https://doi.org/10.1111/j.1467-2979.2011.00430.x>

In the domain of decision-support tools for the management of marine fish resources, considerable attention has been paid to the development of models explaining how fish stocks change over space and time. In most models, fishing effort is assumed to be exogenous and determined by factors such as management. Increasingly, there has been a call for bio-economic models to also account for the dynamics of fishing fleets, recognizing that fishers respond to changing environmental, institutional and economic conditions. A growing literature has sought to explicitly model the endogenous determinants of the capacity of fishing fleets, the intensity of its use and its temporal and spatial allocation across fishing opportunities. We review this literature, focusing on empirical applications of the behavioural models that have been put forward to explain and predict observed fleet dynamics. We find that although economic factors are usually included as a dominant driver in most studies, this is often based on the use of proxy variables for the key economic drivers, for which adequate data are lacking. Also, while many studies acknowledge that social and social-psychological factors play a significant role in explaining observed fishing behaviour, their inclusion in fishing fleet dynamic models is still very limited. Progress in this domain can only be achieved via the development of multidisciplinary research programmes focusing on applied quantitative analysis of the drivers of fishing fleet dynamics.

Velazquez-Abunader, I., Salas, S., & Cabrera, M. A. (2013). Differential Catchability by Zone, Fleet, and Size: The Case of the Red Octopus (*Octopus maya*) and Common Octopus (*Octopus vulgaris*) Fishery in Yucatan, Mexico. *Journal of Shellfish Research*, 32(3), 845-854. <https://doi.org/10.2983/035.032.0328>

Catchability (q) is a key parameter for the assessment and management of stocks because it is widely used to estimate other parameters such as fishing mortality and resource abundance. However, the common assumption in fisheries assessment that q remains constant through time, individual size, and space can mask the effect of fishing gear, or fleet, when applicable, and the behavior of the organisms, especially when different behavior can be portrayed by different components of the population structure. In the current study, the parameter q was evaluated for the octopus fishery (*Octopus maya* and *Octopus vulgaris*) in Yucatan, Mexico, using two deterministic techniques. In the first, q is assumed to be constant by size, age, and type of fleet, whereas the second technique assumes different sources of variation in q associated with the size of individuals, fleet characteristics, and fishing zone. Results suggest that q estimated using the second technique provides information that allows understanding the effect of fishing gear, fleets, and fishing sites at different levels of the population structure. Differences were observed in the patterns of q among fishing zones, with a high vulnerability of small organisms in the central and western zones of the study area throughout the fishing season, whereas the opposite was found in the eastern zone. Differences were also observed in the catchability of

octopuses by fleet and species. The results suggest the presence of multiple intra-annual cohorts, which are not considered if q is assumed constant, as currently applies for the official assessment of the resources, with the corresponding fisheries management implications. The results are explained within this framework, and the potential effects of sequential externalities are discussed.

Watson, J. T., Haynie, A. C., Sullivan, P. J., Perruso, L., O'Farrell, S., Sanchirico, J. N., & Mueter, F. J. (2018). Vessel Monitoring Systems (VMS) Reveal an Increase in Fishing Efficiency Following Regulatory Changes in a Demersal Longline Fishery. *Fisheries Research*, 207, 85-94.
<https://doi.org/10.1016/j.fishres.2018.06.006>

A global expansion of satellite-based monitoring is making fisher behavioral responses to management actions increasingly observable. However, such data have been underutilized in evaluating the impacts of fishing on target and non-target fish stocks or the ramifications of management strategies on fishers. We demonstrate how vessel monitoring system (VMS) data can provide a suite of metrics (such as effort) for improving inputs to stock assessments, dynamic delineation of fishing grounds, and evaluation of regulatory or other (e.g., climatic) impacts on fisher performance. Using > 1 million VMS records from the Gulf of Mexico grouper-tilefish demersal longline fishery, we first develop a generalized additive modeling approach that predicts fishing duration with similar to 85% accuracy. We combine model predictions with logbook data to compare the fishery before and after implementation of a suite of regulatory changes (e.g., a shift to catch share management). We find a large-scale reduction in fleet size, accompanied by reduced fishing effort (duration * number of hooks), shorter trips, lower operational expenses, higher catch rates, and more earnings for those vessels that remained in the fishery. We discuss how the combination of VMS and associated metrics can be expanded for use in management strategy evaluation, parameterizing economic models of fisher behavior, improving fishery-dependent stock assessment indices, and deriving socioeconomic indicators in fisheries worldwide.

Section IV: Surveys

Baelde, P. (2001). Fishers' Description of Changes in Fishing Gear and Fishing Practices in the Australian South East Trawl Fishery. *Marine and Freshwater Research*, 52(4), 411-417.
<https://doi.org/10.1071/mf99149>

Between the mid 1980s and early 1990s, the concurrence of three major events significantly altered the structure and dynamics of the demersal trawl sector in the Australian South-East Fishery (SEF). These events included marked technological improvement, severe decline of major fish stocks and introduction of an Individual Transferable Quota system. They have led to a switch from maximizing catch volume to maximizing catch composition and quotas, with important associated changes in fishing practices and catches. To better understand these changes and their effect on stock assessment and management, an industry survey asked SEF trawl fishers to describe their fishing gear and fishing practices in detail. This paper is a qualitative synthesis of current trends in fishing that most significantly affect the single-species, logbook-dependent assessment and management of the fishery. It demonstrates how effective collaboration between scientists and fishers can benefit fisheries research

and management, by helping scientists make more informed analysis and interpretations of fisheries data. Extra keywords: industry information, multi-species fishery, ITQ management.

Cinner, J. E., Folke, C., Daw, T., & Hicks, C. C. (2011). Responding to Change: Using Scenarios to Understand How Socioeconomic Factors May Influence Amplifying or Dampening Exploitation Feedbacks among Tanzanian Fishers. *Global Environmental Change-Human and Policy Dimensions*, 21(1), 7-12. <https://doi.org/10.1016/j.gloenvcha.2010.09.001>

Environmental change often requires societies to adapt. In some instances, these adaptations can create feedbacks that amplify the change. Alternatively, other adaptations may dampen the change. We used semi-structured interviews with 240 fishers from nine Tanzanian coastal communities to explore responses to four hypothetical scenarios of increasingly severe declines in their average catch (10%, 20%, 30% and 50%). Overall, a higher proportion of fishers said they would respond to decline using amplifying adaptations (such as fishing harder) than dampening adaptations (such as reducing effort), particularly in the scenarios with lower levels of decline. We used a redundancy analysis to explore whether certain types of responses were related to the fishers' socioeconomic characteristics. Fishers that would employ amplifying responses had greater economic wealth but lacked options. Fishers who would adopt dampening responses possessed characteristics associated with having livelihood options. Fishers who would adopt neither amplifying nor dampening responses were less likely to belong to community groups and sold the largest proportion of their catch. This study provides novel contributions by differentiating aspects of adaptive capacity that will amplify versus dampen environmental change and by highlighting what the resource users' themselves say regarding responding to environmental change. Although direct policy application is limited by the study's hypothetical scenario nature, it provides a good beginning to incorporating resource users' voices into such policy discussions.

Fitzpatrick, M., Maravelias, C. D., Eigaard, O. R., Hynes, S., & Reid, D. (2017). Fisher's Preferences and Trade-Offs between Management Options. *Fish and Fisheries*, 18(5), 795-807. <https://doi.org/10.1111/faf.12204>

Failure to understand the potential responses of fishers to management measures creates a significant risk of revisiting the familiar scenario of perverse and unintended consequences of those measures. This paper reports on a choice experiment survey to evaluate fisher's preferences for various management measures proposed under the EU Common Fisheries Policy (CFP) reform process, but the conclusions have wider relevance as similar measures are used by comparable fleets in fisheries globally. The survey was conducted with fishers involved in mixed pelagic and demersal fisheries in Ireland, pelagic fisheries in Denmark and demersal fisheries in Greece. Fisheries management policies were characterized by five attributes designed both to cover the principal CFP reform proposals and to integrate ecological, social, economic and institutional factors affecting fisher's decisions. The study uses a random utility modelling framework to reveal the preferences of the fishers across the alternative policy attributes. Results show that while there are generally preferences both for healthy stocks and for maintaining the importance of fishing to the local community, strong interfishery preference differences exist. These differences are most notable in relation to a discard ban and to the use of individual transferable fishing rights, favoured in Denmark, but not in Ireland for instance. The strength of these interfishery differences supports the assertion that there are no panaceas in fisheries management and that solutions should be tailored

within the context of specific fisheries. Not doing so could create a significant risk of inappropriately managed fisheries that may lead to unsustainable outcomes.

Griffiths, S. P., Pollock, K. H., Lyle, J. M., Pepperell, J. G., Tonks, M. L., & Sawynok, W. (2010). Following the Chain to Elusive Anglers. *Fish and Fisheries*, 11(2), 220-228. <https://doi.org/10.1111/j.1467-2979.2009.00354.x>

Obtaining reliable estimates of important parameters from recreational fisheries is problematic but critical for stock assessment and effective resource management. Sampling methodologies based on traditional design-based sampling theory, is inadequate in obtaining representative catch and effort data, social or demographical characterization, or fisher behaviour from small hard-to-reach components within recreational fisheries (e. g. specialized sport fisheries) that may account for the majority of the catch for some species. A model-based approach to sampling is necessary. Researchers in other disciplines including epidemiology and social sciences routinely survey rare or 'hidden' populations within the general community by penetration of social networks rather than by interception of individuals. We encourage fisheries researchers to rethink survey designs and consider the social elements of recreational fishing. Employing chain-referral methods, such as respondent-driven sampling (RDS), may be a statistically robust and cost-effective option for sampling elusive sub-elements within recreational fisheries. Chain-referral sampling methodology is outlined and an example of a complemented 'RDS-recapture' survey design is introduced as a cost-effective application to estimating total catch in recreational fisheries.

Hickley, P., & Tompkins, H. (1998). *Recreational Fisheries: Social, Economic, and Management Aspects*: Fishing News Books Oxford, UK. Retrieved from <https://www.wiley.com/en-us/Recreational+Fisheries%3A+Social%2C+Economic+and+Management+Aspects-p-9780852382486>

This valuable collection of overview papers and case studies, produced by the European Inland Fisheries and Advisory Commission (EIFAC) for FAO, brings together international experts to examine all aspects of recreational fisheries in inland waters including: - current status and trends in recreational fisheries; - interactions between recreational fisheries and other sectors; - socio-economic aspects of recreational fisheries; - criteria for the management of recreational fisheries - priorities for research and development including education and training; - the future of recreational fisheries over the next decade An attempt is made to identify the factors which influence, enhance and inhibit the present use and future development of recreational fisheries, to develop strategic guidelines for the effective management of recreational fisheries, and to recognise best practice for fishermen taking part in recreational fishing.

Kramer, R. W., Mann, B. Q., Dunlop, S. W., Mann-Lang, J. B., & Robertson-Andersson, D. (2017). Changes in Recreational Shore Anglers' Attitudes Towards, and Awareness of, Linefish Management Along the Kwazulu-Natal Coast, South Africa. *African Journal of Marine Science*, 39(3), 327-337. <https://doi.org/10.2989/1814232x.2017.1373704>

Management of recreational fisheries cannot be based on biological and stock assessment data alone but needs to include appropriate social aspects (including knowledge, attitudes and behaviour) of

anglers within the fishery. The primary purpose of this study was to evaluate and complement existing recreational fisheries research, through the analysis of demographic and psychographic angler attributes collected from two independent, shore-based snapshot monitoring surveys conducted on the KwaZulu-Natal (KZN) coastline of South Africa, in 1994-1996 and 2009-2010. Results show significant changes between the two survey events in the demographics of anglers (including ethnic composition, age distribution, years of fishing experience and employment status) participating in the KZN shore-based linefishery. Traditional management regulations (minimum size limits, daily bag limits and closed seasons), though appearing to have support, have had limited effectiveness, based on the increased levels of admitted non-compliance and poor knowledge of regulations for target species. Anglers in both surveys believed that catches had declined over the years, with overfishing being the most common reason given. The results are discussed in the context of changing management practices in the KZN recreational shore-based linefishery. The implications of changes in fisheries management policies and responsibilities along the KZN coast are highlighted.

Kronen, M., Sauni, S., Magron, F., & Fay-Sauni, L. (2006). *Status of Reef and Lagoon Resources in the South Pacific—the Influence of Socioeconomic Factors*. Paper presented at the Proceedings of the 10th International Coral Reef Symposium. Retrieved from http://www.spc.int/DigitalLibrary/Doc/FAME/Reports/Kronen_06_Status.pdf

Poor knowledge on status of reef fisheries, as well as extent and impact of subsistence fisheries challenges design and implementation of effective fisheries management aiming at sustainable resource use in the South Pacific. This paper presents experiences and results made in the framework of the multi- and interdisciplinary PROCFish/C project that is funded by the European Union. The project aims at establishing a regional database on status and use of coastal marine resources and the identification of indicators that will help to better monitor the interactions between both. The two major components of the project, resource and socioeconomic surveys, collect both data according to a fisheries classification system to permit joint data analysis. The socioeconomic component does not only furnishes data that is compliant with ecological and resource data but also uncovers site specific mechanisms, in particular interrelations between market-resource- and sociocultural attitudes. Case studies are presented from fisheries communities in Tonga, Fiji and French Polynesia to highlight that appropriate and thus effective policies and fisheries management projects require not only knowledge on the resource, but also on fishing and marketing systems. Fisheries in all three case studies are affected by the dualisms of modern, cash based economic and traditional, non-monetary valorization mechanisms. The Tongan case study illuminates the interplay between sociocultural attitudes and market as improved income incentives provided by urban markets trigger adoption of more efficient fishing strategies. The live rock study from Fiji shows that creating awareness and moral barriers may be a more effective tool in fisheries management than providing facts from research only. The combination of traditional value systems, resource availability and marketing mechanisms that determine not only exploitation but also commercialisation of certain coastal resources is demonstrated by the case study from French Polynesia. Results show that the better understanding of socioeconomic mechanisms will help fisheries managers further understand the manipulative forces of sociocultural attitudinal factors in specific situations to foster or to reduce pressure of specific reef and lagoon fisheries.

Kuster, C., Vuki, V. C., & Zann, L. P. (2005). Long-Term Trends in Subsistence Fishing Patterns and Coral Reef Fisheries Yield from a Remote Fijian Island. *Fisheries Research*, 76(2), 221-228. <https://doi.org/10.1016/j.fishres.2005.06.011>

Household and seafood consumption surveys were conducted on the Fijian island of Ono-i-Lau to examine changes in subsistence fishing patterns and the quantity and composition of yield from the fishery, over a 20-year period from 1982 to 2002. It was found that the transition from traditional outrigger canoes to outboard-powered vessels has caused a dramatic increase in catch rate. This has resulted in a reduction in fishing effort, rather than an increase fisheries yield, as the fishery remains governed by subsistence needs and population size. The introduction of fishing technology has had more of a social impact, rendering the traditional shore-based fishing conducted by women less important. This study indicates that the reefs of Ono-i-Lau have sustained a yield of between 2.9 and 3.7 tonnes km⁽⁻²⁾ year⁽⁻¹⁾ of reef-associated fish over the 20-year period. This provides a useful reference point from which to compare other reef fisheries in the region. The findings of this study also support the argument that non-selective harvesting of finfish can minimize the probability of ecosystem shifts.

Lunn, K. E., & Dearden, P. (2006). Monitoring Small-Scale Marine Fisheries: An Example from Thailand's Ko Chang Archipelago. *Fisheries Research*, 77(1), 60-71. <https://doi.org/10.1016/j.fishres.2005.08.009>

Small-scale fisheries provide food and income to millions of people worldwide, yet these fisheries are generally poorly documented and their impacts not well understood. Improved documentation of these fisheries is needed to gauge global trends, identify the threats to their sustainability, and assess management options. Combining semi-structured interviews and participant observation, this study provides baseline information about the nature and scale of small-scale fisheries in the Ko Chang archipelago, Thailand, as a first step towards instituting a monitoring and management strategy for the area. Although the area has been designated as a "no-take" Marine National Park, small-scale fisheries have continued virtually unabated within the park's boundaries. Small-scale fishers living in the park are involved primarily in the shrimp trammel net, squid trap, crab trap, fish gill net, hook-and-line, and reef fish trap fisheries. Small-scale fishing boats operating out of villages on Ko Chang and Ko Maisi Yai worked for an estimated 38,000 days/year and took 330,000 kg/year of target fish and invertebrates, based on extrapolations from interviews. Observed catches of target species were, however, an average of 42-64% lower than fishers' reported catches for the fisheries in which both data collection methods could be used. Such a finding suggests that future monitoring should rely on observational techniques to assess the catches and efforts of small-scale participants. Given the area's status as a national park, regular monitoring of the small-scale fisheries should be undertaken and multiple-use zoning be considered.

O'Regan, S. M. (2015). Harvesters' Perspectives on the Management of British Columbia's Giant Red Sea Cucumber Fishery. *Marine Policy*, 51, 103-110. <https://doi.org/10.1016/j.marpol.2014.07.025>

In recent decades, sea cucumber fisheries have rapidly expanded worldwide to meet rising demand in Asian markets. Catch trends have often followed a boom-and-bust trajectory and skyrocketing sea cucumber value has often spurred fishery development that outpaced adequate biological research for informed stock assessment. Currently, the dive fishery for Giant red sea cucumber (*Parastichopus californicus*) in British Columbia, Canada is considered moderately exploited. However, basic population parameters such as recruitment and mortality rates are still largely unknown, creating important sources of uncertainty in the fishery's stock assessment model. This study presents the results of an interview-based survey of experienced commercial harvesters' (1) perceptions of local trends in sea

cucumber abundance, size, and fishing effort (CPUE), and (2) perceptions of management efficacy. The majority of harvesters perceived abundance (14/20) and CPUE (15/20) to have declined over their careers, and half of the harvesters reported decreased sea cucumber size. The harvesters most commonly cited overfishing as the most pressing problem facing the fishery (13/20), and the majority felt that Fisheries and Oceans Canada (DFO) needed to lower licence and/or area quotas to avoid further declines. Despite many knowledge gaps in the fishery, almost all harvesters (16/20) perceived that they are not adequately consulted and their concerns are not adequately considered by DFO. These results suggest a disjoint between DFO forecasts and perceived local sea cucumber trends, and highlight that the fishery may lack a resource-rights framework with adequate checks to decouple fishing pressure from increasing global market value and demand. Maintaining the long-term health of the BC sea cucumber fishery may depend on working more closely with harvesters to inform future management decisions and, ideally, moving towards a harvester-owned-and-operated licencing system that can better integrate the feedback that comes from attachment to place.

Ryan, K. L., Trinnie, F. I., Jones, R., Hart, A. M., & Wise, B. S. (2016). Recreational Fisheries Data Requirements for Monitoring Catch Shares. *Fisheries Management and Ecology*, 23(3-4), 218-233. <https://doi.org/10.1111/fme.12151>

Catch sharing among fishing sectors requires credible data for decision-making, allocation and management. Integrated Fisheries Management in Western Australia formally allocates allowable catch for Western Rock Lobster (WRL) (*Panulirus cygnus*) with 95% commercial and 5% recreational; Roe's abalone (*Haliotis roei*) with 36 t commercial and 40 t recreational; and West Coast Demersal Scalefish (WCDS) with 64% commercial and 36% recreational. While commercial catch is obtained from statutory returns, estimates of recreational catches from surveys depend upon spatial and temporal scales of the resource and fishing activity. WRL is a single-species, licensed recreational fishery operating across large spatial and temporal scales. Mail surveys supplemented with occasional phone-recall surveys provide cost-effective monitoring. Roe's abalone is a single-species, licensed recreational fishery operating over restricted spatial and temporal scales appropriate for aerial-access surveys. The WCDS recreational fishery targets multiple species across large spatial and temporal scales. The introduction of charter logbooks and a Recreational Fishing from Boat Licence has provided the basis for monitoring charter and private boat-based recreational fishing. Monitoring allocations is ongoing, with routine surveys required to provide catch estimates with a known confidence. This study highlights the application and importance of surveys in providing timely and accurate data for formal catch sharing.

Sparrevohn, C. R., & Storr-Paulsen, M. (2012). Using Interview-Based Recall Surveys to Estimate Cod *Gadus morhua* and Eel *Anguilla anguilla* Harvest in Danish Recreational Fishing. *ICES Journal of Marine Science*, 69(2), 323-330. <https://doi.org/10.1093/icesjms/fss005>

Marine recreational fishing is a popular outdoor activity in Denmark, practised by both anglers and passive gear fishers. However, the impact on the targeted stocks is unknown, so to estimate the 2009 harvest of cod *Gadus morhua* and eel *Anguilla anguilla*, two separate interview-based surveys were initiated and carried out in 2009/2010. The first recall survey exclusively targeted fishers who had been issued with the mandatory Danish fishing licence. The second survey was designed to identify those who fish without a licence. It was estimated that 1231 t of cod were harvested in 2009, corresponding to 4.8% of the entire Danish cod yield (recreational harvest + commercial landings). Area differences were found, and, in certain areas, the recreational harvest of cod accounted for more than 30% of the total

yield. The majority (81%) of the recreational cod harvest was taken by anglers. Eels, however, are almost exclusively caught with passive gear (fykenets) and a total of 104 t year⁻¹ was harvested, which corresponds to 19% of the entire Danish eel yield. The inclusion of the harvest taken by fishers without a valid licence was important and added almost 20% to the estimated harvest.

Volstad, J. H., Afonso, P. S., Baloi, A. P., de Premegi, N., Meisfjord, J., & Cardinale, M. (2014). Probability-Based Survey to Monitor Catch and Effort in Coastal Small-Scale Fisheries. *Fisheries Research*, 151, 39-46. <https://doi.org/10.1016/j.fishres.2013.11.016>

Catch and effort data form an important, and often the only, source of data for stock assessment and management of marine resources in developing countries. Population parameters and management quantities important for stock assessment are often estimated by fitting production models to standardized series of catch-per-unit-effort (CPUE). Such basic information is notoriously hard to obtain for small-scale fisheries because of the large spatial and temporal variability in effort, numerous landing sites, and limited access for biological data collections. In this paper, we present a probability-based survey sampling method for the monitoring of the small-scale fisheries in Mozambique. The survey is an on-site intercept design, which supports the estimation of annual catch and effort and other key statistics for the coastal fisheries in a sampled geographic area. Estimates of catch and effort, with associated relative standard errors, for beach seine fisheries in the district of Angoche and for Inhambane Bay are used to illustrate the applicability of the methodology. The flexible survey design is nowadays used to monitor small-scale fisheries in all provinces of Mozambique. We also present a method for obtaining approximate estimates of total catches for a study area when the coverage of fishing centers is incomplete. Survey estimates of the average proportion of beach seines that are actively used in fishing by month are used to adjust fishing effort derived from census data on the total number of beach seines for fishing centers not covered in the survey. The adjusted effort is then combined with estimates of CPUE to estimate the total catches for fishing centers that are not covered in the survey. Results suggest that the common method (often referred to as a frame survey) for studying artisanal fisheries that relies on effort estimates from a census of landing sites at some intervals in time, combined with CPUE from regular sampling from a small subset of fishing centers selected ad-hoc would introduce substantial bias of variable magnitude. The reason is that effort in small-scale fisheries strongly depends on weather conditions and socio-economic factors.

Zarauz, L., Ruiz, J., Urtizbera, A., Andonegi, E., Mugerza, E., & Artetxe, I. (2015). Comparing Different Survey Methods to Estimate European Sea Bass Recreational Catches in the Basque Country. *ICES Journal of Marine Science*, 72(4), 1181-1191. <https://doi.org/10.1093/icesjms/fsv054>

This is the first study that estimates sea bass recreational catches in the Basque Country including fishers from shore, boat, and spearfishing. Three different offsite survey methods were used (e-mail, phone, and post) and their performance was compared. Estimates were different depending on the survey method used. Total catch estimates for shore fishing were 129, 156, and 351 tonnes for e-mail, phone, and post surveys, respectively. For boat fishing, estimates varied from 5 tonnes (phone) to 13 tonnes (e-mail and post). For spearfishing, only e-mail surveys were performed and total catch was estimated in 13 tonnes. Potential representation and measurement bias of each survey method were analysed. It was concluded that post surveys assured a full coverage of the target population, but showed very low response rates. Telephone surveys presented the highest response rates, but lower coverage of the target population. E-mail surveys had a low coverage and a low response rate, but it was the cheapest

method, and allowed the largest sample size. All surveys methods were affected by recall bias. Recommendations are made about how to improve the surveys (increasing coverage, reducing non-response, and recall bias) to set up a routine cost-effective monitoring programme for Basque recreational fisheries. Results show that estimated sea bass recreational catches are comparable to commercial catches, which emphasize the relevance of sampling recreational fishing on a routine basis and including this information into the stock assessment and management processes.

Section V: Cost Effect on Stock Assessments

Caputi, N., de Lestang, S., Reid, C., Hesp, A., & How, J. (2015). Maximum Economic Yield of the Western Rock Lobster Fishery of Western Australia after Moving from Effort to Quota Control. *Marine Policy*, 51, 452-464. <https://doi.org/10.1016/j.marpol.2014.10.006>

The western rock lobster (*Panulirus cygnus*) fishery is Australia's most valuable single-species fishery, worth AUD\$200-\$400 million annually. Stock assessment for this fishery utilises the puerulus settlement to predict recruitment to the fishery 3-4 years later. This predictive ability has been particularly useful recently, due to an unprecedented period of low settlement between 2006/07 and 2012/13. Pre-emptive management action (similar to 70% effort reduction) was taken to provide greater protection to the breeding stock which also moved the fishery to the maximum economic yield (MEY) level of effort for the projected recruitment. In 2010/11, the fishery moved from an effort-controlled to a quota-controlled fishery, which led to changes in fishing practices resulting in reductions in fishing costs and increases in lobster prices of about US\$16/kg. This provided a unique opportunity to compare an MEY assessment under effort and quota controls. The MEY assessment under quota controls for a 5-year period indicated that annual harvest rates of 37-47% of legal biomass will achieve catches of 5780-7370 t. in 2014. This MEY target harvest range, which complements existing sustainability reference points based on egg production, is robust to a range of costs, prices and profit discount rates. This catch range enables industry/managers to take into account marketing implications and social issues (e.g. employment) in quota setting and therefore could be considered a socio-economic target. The MEY level of fishing has increased egg production to well above threshold levels that were based on maximum sustainable yield, providing the fishery with increased resilience when faced with environmental perturbations. This enables consideration for relaxing some existing biological controls, e.g. setose (mature) females, females above a maximum size, and lobsters 76-77 mm carapace length. The relaxation of these controls is estimated to increase profits by about AUD\$15 million annually due to higher catch rates and reduced fishing effort while maintaining egg production well above threshold levels.

Ceriola, L., Accadia, P., Mannini, P., Massa, F., Milone, N., & Ungaro, N. (2008). A Bio-Economic Indicators Suite for the Appraisal of the Demersal Trawl Fishery in the Southern Adriatic Sea (Central Mediterranean). *Fisheries Research*, 92(2-3), 255-267. <https://doi.org/10.1016/j.fishres.2008.01.017>

The state of demersal fishery in the Southern Adriatic Sea (GFCM-GSA 18, Central Mediterranean), years 1996-2003, from a biological, social and economic point of view was analysed using 47 indicators: 22

biological indicators obtained from fishery-independent data through yearly experimental bottom trawl surveys ("Meditis" Programme), and 25 socio-economic indicators estimated from fishery-dependent data, available from the monitoring system of the Italian Institute for Economic Research on Fisheries and Aquaculture (IREPA). Biological indicators were applied for "single-species" (Eledone cirrhosa, E. moschata, Illex coindetti, Merluccius merluccius, Mullus barbatus, Nephrops norvegicus, Parapenaeus longirostris, Raja clavata, Zeus faber) and for "multi-species" analysis. Economic indicators describing economic performance, productivity, costs and prices, and the overall economic sustainability of fishery were estimated. Social indicators and a general indicator summarising social sustainability were also considered. Indicators' values were displayed using the Traffic Light system. Both fishery-independent and fishery-dependent indicators highlighted a progressive decline of the trawl fishery system in the GSA 18. This decline was mainly related to the ongoing depletion of the traditional fishery target species (mostly long-living, late-maturing species) partially replaced by the increase of traditional accessory species (generally short-living species), as well as to the reduction of productivity and increasing costs. The whole procedure was proposed as a contribution to the identification and applicability of bio-economic indicators for fishery management purposes.

Dichmont, C. M., Pascoe, S., Kompas, T., Punt, A. E., & Deng, R. (2010). On Implementing Maximum Economic Yield in Commercial Fisheries. *Proceedings of the National Academy of Sciences*, 107(1), 16. <https://doi.org/10.1073/pnas.0912091107>

Economists have long argued that a fishery that maximizes its economic potential usually will also satisfy its conservation objectives. Recently, maximum economic yield (MEY) has been identified as a primary management objective for Australian fisheries and is under consideration elsewhere. However, first attempts at estimating MEY as an actual management target for a real fishery (rather than a conceptual or theoretical exercise) have highlighted some substantial complexities generally unconsidered by fisheries economists. Here, we highlight some of the main issues encountered in our experience and their implications for estimating and transitioning to MEY. Using a bioeconomic model of an Australian fishery for which MEY is the management target, we note that unconstrained optimization may result in effort trajectories that would not be acceptable to industry or managers. Different assumptions regarding appropriate constraints result in different outcomes, each of which may be considered a valid MEY. Similarly, alternative treatments of prices and costs may result in differing estimates of MEY and their associated effort trajectories. To develop an implementable management strategy in an adaptive management framework, a set of assumptions must be agreed among scientists, economists, and industry and managers, indicating that operationalizing MEY is not simply a matter of estimating the numbers but requires strong industry commitment and involvement.

Emery, T. J., Gardner, C., Hartmann, K., & Cartwright, I. (2017). Incorporating Economics into Fisheries Management Frameworks in Australia. *Marine Policy*, 77, 136-143. <https://doi.org/10.1016/j.marpol.2016.12.018>

A large gap has been identified between the current and optimal economic performance of wild-capture commercial fisheries in Australia. Economic approaches have the potential to assist fisheries to bridge this gap, such as bio-economic models that combine biology with fishing costs to evaluate the economic performance of a broad range of management measures. Economic objectives are prevalent in overarching Australian fisheries legislation, however economic data is often not collected and economic analyses or instruments not broadly applied. This paper reviews selected Australian fisheries to

demonstrate the accrued economic benefits from applying formal bio-economic models and conducting empirical analyses of the impact of supply on product value. Challenges to the implementation and continued use of economic analyses and instruments are discussed including: (i) short-term transition costs and associated trade-offs between ecological, economic, social and political objectives; (ii) scarce logistical and financial capacity to collect and analyse economic data; (iii) a lack of desire among industry to change and transition to economic targets such as maximum economic yield (MEY), particularly when it is associated with lower catches; and (iv) a lack of economic literacy among fisheries managers and industry. It is contended that many of these challenges initially arise from an absence of clearly identified and prioritised objectives within overarching legislation and management plans. Once objectives are prioritised, limited resources can be allocated more efficiently to improve data collection, economic analysis and increase awareness as well as education of managers and industry.

Hesp, S., Caputi, N., Penn, J., Kangas, M., Sporer, E., Hogan, B., & Clement, J. (2017). Improving Fleet Efficiency to Maximise Economic Yield in a Western Australian Prawn Fishery. *Marine Policy*, 86, 82-93. <https://doi.org/10.1016/j.marpol.2017.09.006>

The Shark Bay trawl fishery is Western Australia's most valuable prawn fishery (worth AUD\$25 million in 2014). The 18-vessel fleet targets western king prawns (*Penaeus latisulcatus*), brown tiger prawns (*P. esculentus*) and also retains saucer scallops (*Ylistrumballoti*) and blue swimmer crabs (*Portunus armatus*). Increased fuel prices, falling prawn prices and lower catches of other species, following extreme environmental events, have impacted fishery profits. A biomass dynamics model with an economic component indicated that total revenue levels start to decline when annual effort increases beyond similar to 200 fishing days per boat. Annual effort required to achieve MEY, when based solely on prawn fishing, is 115-150 days per boat after accounting for fixed and variable fishing costs and annual fishing efficiency increases of 1-2%. From 2007-2014, the adjusted effort was 188-192 days per boat. Fishing occurred between March and November during 7-8 fishing periods, separated by 5-8 day (low catchability) moon closure periods. An empirical daily profit assessment (2007-2015), accounting for recruitment variation, daily prawn size compositions, monthly market prices for different prawn species and sizes, and daily fishing costs, showed vessels made profits on similar to 115-160 days and losses on similar to 15-55 days per year, when fishing occurred near the full moon. The fishery benefitted in 2013-2015 by starting later in the year and better targeting within-season effort. This management strategy within the effort-control framework, which improved profitability, maintained higher spawning stocks and reduced ecosystem fishing impacts, has wider application in prawn fishery management.

Pascoe, S., Dichmont, C. M., Vieira, S., Kompas, T., Buckworth, R. C., & Carter, D. (2013). A Retrospective Evaluation of Sustainable Yields for Australia's Northern Prawn Fishery: An Alternative View. *Fisheries*, 38(11), 502-508. <https://doi.org/10.1080/03632415.2013.848342>

The increasing interest in maximum economic yield (MEY) as a management target has been accompanied by considerable debate as to how MEY should be determined. Different interpretations as to how economic costs are treated may lead to different outcomes. For example, a recent paper by Wang and Wang (2012b) provided a retrospective analysis of a recent buyback program in a major Australian fishery aimed at moving the fishery to MEY and concluded that greater economic benefits would have been achieved had the buyback not taken place. However, the economic assumptions underlying this result are debatable. In this article, we provide our own analysis using corrected

economic parameters and suggest that, had the buyback not taken place, industry profits from 2006 to 2009 would have been \$22-25 million lower. These new findings are placed in the context of the events that led to the buyback taking place and we conclude that the buyback resulted in substantial benefits to the industry.

Pascoe, S., Hutton, T., Coglan, L., & Nguyen, V. Q. (2018). Implications of Efficiency and Productivity Change over the Season for Setting MEY-Based Trigger Targets. *Australian Journal of Agricultural and Resource Economics*, 62(2), 199-216. <https://doi.org/10.1111/1467-8489.12244>

The banana prawn component of Australia's Northern Prawn Fishery (NPF) is currently managed through the use of annually updated trigger catch rates as a means of achieving maximum economic yield (MEY) in the fishery, taking into account the estimated price and cost components for that season. The estimation of these target catch rates is based on the assumption of relative homogeneity of the fleet in terms of efficiency, productivity and cost structure. In this study, these assumptions are examined through the estimation of a stochastic production frontier. While technical efficiency varies between vessels, average efficiency is relatively constant over the fishing season. However, average productivity of the fleet increases, with smaller vessels (in terms of engine power) exiting the fishery earlier. This would likely increase the average cost of fishing towards the end of the season, with implications for setting the target catch rate. Based on a standard assumption as to the relationship between costs and vessel size, we find that the MEY target catch rates are most likely currently underestimated. However, the implementation of a precautionary minimum catch rate (which is above the MEY target catch rates for recent years) has maintained the fishery at a profitable level.

Pascoe, S., Thebaud, O., & Vieira, S. (2014). Estimating Proxy Economic Target Reference Points in Data-Poor Single-Species Fisheries. *Marine and Coastal Fisheries*, 6(1), 247-259. <https://doi.org/10.1080/19425120.2014.966215>

Bioeconomic models have been developed and applied to a range of fisheries around the world. However, an even greater number of fisheries are relatively data poor, and development of traditional bioeconomic models is not feasible. For small-scale fisheries, the cost of data collection and model development may exceed the additional value these models may generate. Fisheries biologists have grappled with similar issues and have developed a range of data-poor methods for estimating reference points related to fishing mortality based on life history characteristics and other indicators. In other cases, catch and effort data may be sufficient to estimate sustainable biomass levels. However, model-derived economic target reference points require robust biological models as well as appropriate economic information, both of which are often unavailable. In this paper, we extend the data-poor work to move from biological to economic target reference points for single-species fisheries. We show that the relationship between economic (maximum economic yield) and biological (maximum sustainable yield) reference points depends primarily on the cost : revenue ratio, and that, where unavailable, these can be inferred from fisheries characteristics. We show that good estimates of biomass- and effort-based economic target reference points can be achieved with limited data. Received September 4, 2013; accepted August 10, 2014

Pascoe, S. D., Sharp, J. A., & Buckworth, R. C. (2016). Modelling Effort Levels in a Sequential Fishery. *ICES Journal of Marine Science*, 73(2), 503-511. <https://doi.org/10.1093/icesjms/fsv170>

Developing bioeconomic models of sequential fisheries is complicated when the two (or more) fisheries overlap temporally. In such cases, each fishery will be affected by the other, so both cannot be properly modelled as separate activities. This has recently become an issue for the Northern Prawn Fishery, in which bioeconomic modelling is used to set management limits. Modelling has focused on the tiger prawn component of the fishery, which mostly occurs in the second half of the year. However, successful management leading to stock recovery has resulted in this fishery now overlapping temporally with the banana prawn fishery, which occurs in the first half of the year. Ideally, an integrated model covering the whole year would be developed, but this is not practical for a number of reasons. In this study, we model the factors driving the level of fishing effort in the banana prawn fishery, which affects, and is affected by, the tiger prawn fishery. As expected, banana prawn fishing effort is driven largely by stock size, fleet size, catch rates, prices, and fuel costs. Effort increases with fleet size, but at a decreasing rate. Further, we find evidence that opportunity cost, namely the ability to fish in the tiger prawn fishery and the price of tiger prawns, also affects the level of effort in the banana prawn fishery.

Punt, A. E., Deng, R. A., Dichmont, C. M., Kompas, T., Venables, W. N., Zhou, S., . . . Kienzle, M. (2010). Integrating Size-Structured Assessment and Bioeconomic Management Advice in Australia's Northern Prawn Fishery. *ICES Journal of Marine Science*, 67(8), 1785-1801. <https://doi.org/10.1093/icesjms/fsq037>

Three species in Australia's northern prawn fishery (*Penaeus semisulcatus*, *P. esculentus*, and *Metapenaeus endeavouri*) are assessed using a size-structured population model that operates on a weekly time-step. The parameters of this multispecies population model are estimated using data on catches, catch rates, length frequency data from surveys and the fishery, and tag release–recapture data. The model allows for the technical interaction among the three species. The results from the multispecies stock assessment are used to calculate the time-series of catches and levels of fishing effort that maximize net present value. The bioeconomic model takes into account costs which are proportional to catches and those which are proportional to fishing effort, as well as fixed costs. The sensitivity of the results is examined by changing the assumptions regarding the values for the economic parameters of the bioeconomic model as well as those on which the assessment are based. The results suggest that fishing effort needs to be reduced in the short term to achieve economic goals, although most stocks are estimated currently to be above the stock size corresponding to maximum sustainable yield. Short-term catches and effort levels are sensitive to model assumptions, and in particular, to trends in prices and costs.

Rodrigues, A. R., Abdallah, P. R., & Gasalla, M. A. (2018). Harvesting Costs and Revenues: Implication of the Performance of Open-Access Industrial Fishing Fleets Off Rio Grande, Brazil. *Marine Policy*, 93, 104-112. <https://doi.org/10.1016/j.marpol.2018.04.008>

In order to assess the performance of major commercial fleets, key factors affecting fishing costs and revenues are provided along with a framework to standardize economic knowledge construction in data-poor fisheries, such as South Brazil's. Additionally, the effects of fuel subsidy policies on profitability were further evaluated among fleets. The unprecedented set of field survey data generated by this study revealed that fuel consumption, fish price, and catch volume were the main factors affecting profitability. Annual gross profit was positive for all fleets. Longliners showed the highest gross

profit margin (29%), while single-bottom-trawlers, close to unviability, showed the lowest (0.9%). Overall, subsidies were ineffective in increasing Rio Grande fleet gross profits and may be masking poor economic performance, primarily for single-bottom-trawlers. Specific policy advice aiming to protect both economic performance and natural resources are discussed, including the importance of economic data collection and cost-benefit analysis.

Wang, Y. G., & Wang, N. (2012). Implications of Gain Functions in Fisheries Management. *Reviews in Fisheries Science*, 20(2), 103-109. <https://doi.org/10.1080/10641262.2012.663421>

The appealing concept of optimal harvesting is often used in fisheries to obtain new management strategies. However, optimality depends on the objective function, which often varies, reflecting the interests of different groups of people. The aim of maximum sustainable yield is to extract the greatest amount of food from replenishable resources in a sustainable way. Maximum sustainable yield may not be desirable from an economic point of view. Maximum economic yield that maximizes the profit of fishing fleets (harvesting sector) but ignores socio-economic benefits such as employment and other positive externalities. It may be more appropriate to use the maximum economic yield that which is based on the value chain of the overall fishing sector, to reflect better society's interests. How to make more efficient use of a fishery for society rather than fishing operators depends critically on the gain function parameters including multiplier effects and inclusion or exclusion of certain costs. In particular, the optimal effort level based on the overall value chain moves closer to the optimal effort for the maximum sustainable yield because of the multiplier effect. These issues are illustrated using the Australian Northern Prawn Fishery.

Section VI: Demographics and Community Vulnerability

Cinner, J. E. (2007). Designing Marine Reserves to Reflect Local Socioeconomic Conditions: Lessons from Long-Enduring Customary Management Systems. *Coral Reefs*, 26(4), 1035-1045. <https://doi.org/10.1007/s00338-007-0213-2>

Coral reef conservation strategies such as marine protected areas have met limited success in many developing countries. Some researchers attribute part of these shortcomings to inadequate attention to the social context of conserving marine resources. To gain insights into applying Western conservation theory more successfully in the socioeconomic context of developing countries, this study examines how long-enduring, customary reef closures appear to reflect local socioeconomic conditions in two Papua New Guinean communities. Attributes of the customary management (including size, shape, permanence, and gear restrictions) are examined in relation to prevailing socioeconomic conditions (including resource users' ability to switch gears, fishing grounds, and occupations). Customary closures in the two communities appear to reflect local socioeconomic circumstances in three ways. First, in situations where people can readily switch between occupations, full closures are acceptable with periodic harvests to benefit from the closure. In comparison, communities with high dependence on the marine resources are more conducive to employing strategies that restrict certain gear types while still allowing others. Second, where there is multiple clan and family spatial ownership of resources, the communities have one closure per clan/family; one large no-take area would have disproportionate

affect on those compared to the rest of the community. In contrast, communities that have joint ownership can establish one large closure as long as there are other areas available to harvest. Third, historical and trade relationships with neighboring communities can influence regulations by creating the need for occasional harvests to provide fish for feasts. This study further demonstrates the importance of understanding the socioeconomic context of factors such as community governance and levels of dependence for the conservation of marine resources.

Cinner, J. E., & McClanahan, T. R. (2006). Socioeconomic Factors That Lead to Overfishing in Small-Scale Coral Reef Fisheries of Papua New Guinea. *Environmental Conservation*, 33(1), 73-80.
<https://doi.org/10.1017/s0376892906002748>

The coral reefs of Papua New Guinea are among the most species diverse in the world, support an important artisanal fishery, but lack an effective national conservation programme. Increased commercialization, population growth, promotion of fisheries development projects, and the live reef food fish trade are expected to increase demand for the country's reef fish. This paper examines how socioeconomic factors affect the condition of the artisanal multi-species coral reef fishery in six sites in Papua New Guinea. Catch characteristics such as diversity, trophic level and body size by landing site were examined along a fishing pressure gradient. Both exogenous factors such as markets and endogenous factors such as fishing pressure were related to the condition of fish catch. In general, the trophic level and lengths of fish captured in Papua New Guinea were relatively high, but were reduced on reefs with high fishing effort near fish markets. Fisheries showed signs of depletion above c. 25 fishing trips per km² per day and the proximity of markets was a better indicator of overfishing than human population size. A cross-scale approach to fisheries management is required in Papua New Guinea to coordinate decentralized local management, limit the intrusion of extractive enterprises, and develop policies that seek to minimize exogenous pressures on marine resources.

Cinner, J. E., McClanahan, T. R., Daw, T. M., Graham, N. A. J., Maina, J., Wilson, S. K., & Hughes, T. P. (2009). Linking Social and Ecological Systems to Sustain Coral Reef Fisheries. *Current Biology*, 19(3), 206-212. <https://doi.org/10.1016/j.cub.2008.11.055>

The ecosystem goods and services provided by coral reefs are critical to the social and economic welfare of hundreds of millions of people, overwhelmingly in developing countries [1]. Widespread reef degradation is severely eroding these goods and services, but the socioeconomic factors shaping the ways that societies use coral reefs are poorly understood [2]. We examine relationships between human population density, a multidimensional index of socioeconomic development, reef complexity, and the condition of coral reef fish populations in five countries across the Indian Ocean. In fished sites, fish biomass was negatively related to human population density, but it was best explained by reef complexity and a U-shaped relationship with socioeconomic development. The biomass of reef fishes was four times lower at locations with intermediate levels of economic development than at locations with both low and high development. In contrast, average biomass inside fishery closures was three times higher than in fished sites and was not associated with socioeconomic development. Sustaining coral reef fisheries requires an integrated approach that uses tools such as protected areas to quickly build reef resources while also building capacities and capital in societies over longer time frames to address the complex underlying causes of reef degradation.

Cinner, J. E., Sutton, S. G., & Bond, T. G. (2007). Socioeconomic Thresholds That Affect Use of Customary Fisheries Management Tools. *Conservation Biology*, 21(6), 1603-1611. <https://doi.org/10.1111/j.1523-1739.2007.00796.x>

Customary forms of resource management, such as taboos, have received considerable attention as a potential basis for conservation initiatives in the Indo-Pacific. Yet little is known about how socioeconomic factors influence the ability of communities to use customary management practices and whether socioeconomic transformations within communities will weaken conservation initiatives with a customary foundation. We used a comparative approach to examine how socioeconomic factors may influence whether communities use customary fisheries management in Papua New Guinea. We examined levels of material wealth (modernization), dependence on marine resources, population, and distance to market in 15 coastal communities. We compared these socioeconomic conditions in 5 communities that used a customary method of closing their fishing ground with 10 communities that did not use this type of management. There were apparent threshold levels of dependence on marine resources, modernization, distance to markets (<16.5 km), and population (>600 people) beyond which communities did not use customary fisheries closures. Nevertheless, economic inequality, rather than mean modernization levels seemed to influence the use of closures. Our results suggest that customary management institutions are not resilient to factors such as population growth and economic modernization. If customary management is to be used as a basis for modern conservation initiatives, cross-scale institutional arrangements such as networks and bridging organizations may be required to help filter the impacts of socioeconomic transformations.

Guillemot, N., Chabanet, P., Kulbicki, M., Vigliola, L., Leopold, M., Jollit, I., & Le Pape, O. (2014). Effects of Fishing on Fish Assemblages in a Coral Reef Ecosystem: From Functional Response to Potential Indicators. *Ecological Indicators*, 43, 227-235. <https://doi.org/10.1016/j.ecolind.2014.02.015>

Many Pacific countries face socio-economic changes, resulting in an increase in fishing pressure on reef fish resources. In coral reef environments, examining the ecological effects of fishing on fish assemblages is generally hampered by the lack of data for both in situ assemblages and fishing activities, and by the difficulty to account for natural variations in assemblages. The responses of fish assemblages to moderate fishing pressure were investigated in two sites of New Caledonia (South Pacific). Habitat structures and fish assemblages were described through in situ multiyear underwater visual surveys to account for spatial and temporal variability. A recent quantification of fishing catches and efforts allowed defining spatial gradients of fishing pressure. Linear models were used to test fishing effects on species richness, density, biomass, length and trophic structure of the whole assemblage, large species, target species, and different ecotrophic guilds. A significant decrease in most metrics was detected when fishing pressure increased. The results obtained for all-species fish metrics were confirmed for target species, large species, carnivores and corallivores trophic guilds and large individuals. This functional modelling approach accounted for the natural variability of local coral reef systems and allowed detecting effects of fishing, although fishing pressure was low to moderate in the surveyed sites. Our results suggest that further modelling development, including control sites, would allow precautionary indicators and strategies to be defined for the monitoring and management of reef fish resources.

Guillemot, N., Leopold, M., Cuif, M., & Chabanet, P. (2009). Characterization and Management of Informal Fisheries Confronted with Socio-Economic Changes in New Caledonia (South Pacific). *Fisheries Research*, 98(1-3), 51-61. <https://doi.org/10.1016/j.fishres.2009.03.013>

On the rural north-west coast of New Caledonia, the settlement of a major mining complex is expected to cause rapid and important socio-economic changes, resulting in significant effects on local fishing practices and their impact on resources. Fisher interviews were conducted in 2007 in this area to estimate fish catches, fishing yields and effort, to define a typology of informal fishing activities (including recreational, subsistence and benefit-aimed fishing), and to describe their spatial distribution. These results allowed the discussion of possible scenarios concerning the evolution of reef fish exploitation in a context of fast growing Population and socio-economic changes. Local reef fisheries were essentially conducted through informal activities: 312 active boats were recorded and their catches reached 169 t/year whereas catches by professional fishers represented only 25 t/year with 4 boats. Practices and fishing yields were very diverse and linked to social, cultural and economic factors. Indigenous (Melanesian) fishers were mainly associated with subsistence and in some cases benefit-aimed activities (with informal commercialization), resulting in cost-benefit practices, important catches and the use of productive gears (gillnets). The fishers living in multi-cultural villages were mostly recreational, characterized by low yields and the use of less effective gears (spear gun, hand line). Fishing grounds were spatially structured according to these modern and traditional practices and their respective target biotopes. The main target families of reef fish were Lethrinidae, Acanthuridae and Mugilidae, the latter being mostly exploited by Melanesian fishers. The overall fishing pressure in the area (0.26t/km²/year) was low compared to other countries in the Pacific. However, its spatial distribution showed that some areas were lightly exploited whereas others were close to overfishing. Results showed that the expected rise in fish demand may lead to unsustainable exploitation levels in the latter zones. The increase in the recreational fishing fleet may also result in additional fishing pressure as well as reef degradations. From a social point of view, the fast economic development of the area is likely to disturb the present informal organization of fisheries and to initiate conflicts over the use of space and resources. Such perspectives call for urgent management measures. This case study therefore provided insights into the complex structure of informal fisheries in insular territories in the Pacific and their possible evolution when confronted with socio-economic changes.

Medley, P. A., Gaudian, G., & Wells, S. (1993). Coral Reef Fisheries Stock Assessment. *Reviews in Fish Biology and Fisheries*, 3(3), 242-285. <https://doi.org/10.1007/bf00043930>

This review concentrates on capture fisheries for finfish, although some of the points made in this paper may be relevant to the management of invertebrates. The extensive literature on fish ecology is reviewed briefly from the point of view of fisheries management and provides background for those not familiar with this area of research. The aim is to see whether studies can suggest any improvements to population models currently used in stock assessment. Using case studies, the wider issues of coral reef fisheries management are then briefly discussed. The coral reef environment is beset by a number of environmental and socio-economic problems which may well eclipse those of traditional stock management.

Melnichuk, M. C., Peterson, E., Elliott, M., & Hilborn, R. (2017). Fisheries Management Impacts on Target Species Status. *Proceedings of the National Academy of Sciences of the United States of America*, 114(1), 178-183. <https://doi.org/10.1073/pnas.1609915114>

Fisheries management systems around the world are highly diverse in their design, operation, and effectiveness at meeting objectives. A variety of management institutions, strategies, and tactics are used across disparate regions, fishing fleets, and taxonomic groups. At a global level, it is unclear which particular management attributes have greatest influence on the status of fished populations, and also unclear which external factors affect the overall success of fisheries management systems. We used expert surveys to characterize the management systems by species of 28 major fishing nations and examined influences of economic, geographic, and fishery-related factors. A Fisheries Management Index, which integrated research, management, enforcement, and socioeconomic attributes, showed wide variation among countries and was strongly affected by per capita gross domestic product (positively) and capacity-enhancing subsidies (negatively). Among 13 management attributes considered, three were particularly influential in whether stock size and fishing mortality are currently in or trending toward desirable states: extensiveness of stock assessments, strength of fishing pressure limits, and comprehensiveness of enforcement programs. These results support arguments that the key to successful fisheries management is the implementation and enforcement of science-based catch or effort limits, and that monetary investment into fisheries can help achieve management objectives if used to limit fishing pressure rather than enhance fishing capacity. Countries with currently less-effective management systems have the greatest potential for improving long-term stock status outcomes and should be the focus of efforts to improve fisheries management globally.

Monteiro, P. V. (2017). The Purse Seine Fishing of Sardine in Portuguese Waters: A Difficult Compromise between Fish Stock Sustainability and Fishing Effort. *Reviews in Fisheries Science & Aquaculture*, 25(3), 218-229. <https://doi.org/10.1080/23308249.2016.1269720>

Many capture fisheries worldwide have declined sharply in recent decades or have already collapsed from overfishing, and major fishing grounds are concentrated in zones threatened by pollution, habitat, and coastal zone modification. In Portugal, the European pilchard or sardine (*Sardina pilchardus*), which is mainly captured by purse seiners (similar to 98%), is among the species most consumed (along with dried and salted cod), and commercially, it is the most important fish landed in national ports. Besides its consumption as fresh, canned sardine stands out among Portuguese seafood major exports. Although sardine has neither total allowable catch (TAC) nor quota, the Portuguese catch limits for sardine are regulated by the International Council for the Exploration of the Sea (ICES) at the request of the European Union (EU). Therefore, in practice, the ICES advice works as a theoretical TAC. The aim of this article is to diagnose the current state of sardine stocks in the areas where the Portuguese seine fishing is exerted and simultaneously assess if the structural changes induced on the purse seining fleet capacity, in response to the management system currently in force for this fishery, are aligned with its sustainable development. Our major findings conclude that sardine stocks are still exploited at levels that jeopardize the Maximum Sustainable Yield (MSY). Once the unavoidable restructuring of the Portuguese purse seine fleet will inevitably increase unemployment among fishers, we also stress the need to reshape the current Community-Led Local Development (CLLD) program, funded under the EU fisheries structural aid, to make it more effective in minimizing the severe social impacts potentially coming out.

Richmond, L., Kotowicz, D., & Hospital, J. (2015). Monitoring Socioeconomic Impacts of Hawai'i's 2010 Bigeye Tuna Closure: Complexities of Local Management in a Global Fishery. *Ocean & Coastal Management*, 106, 87-96. <https://doi.org/10.1016/j.ocecoaman.2015.01.015>

This paper presents the results of a study to monitor the socioeconomic impacts of the first extended closure of the western and central Pacific Ocean (WCPO) bigeye tuna (bigeye) fishery to US longliners from the state of Hawai'i. We applied qualitative and quantitative approaches to examine how diverse members of Hawai'i's bigeye fishery community, including fishermen, a large fish auction, dealers, processors, retailers, consumers, and support industries, perceived and were affected by the constraints of the 40-day closure of the WCPO bigeye fishery at the end of 2010. Our analysis found that there was reduced supply and reduced quality of bigeye landed along with increased prices for bigeye during the closure period. In addition, Hawaii longliners were forced to travel longer distances to fish during the closure. These factors contributed to increased stress and in some cases lost revenue for a variety of individuals and businesses connected to the fishery. We also found that different stakeholder groups responded to the closure in different ways and fish dealers were among those most affected by the closure. However, overall impacts to the bigeye community were not as severe as what had been anticipated at the outset. Several mitigating factors meant this was not a true closure, as US boats could continue to fish for bigeye in the Eastern Pacific Ocean and foreign and dual permitted vessels could still fish in the WCPO. Longline fleet has since benefited from US legislation and federal rules that have prevented any subsequent closures of the fishery. While this relief from closures could stall short term socioeconomic impacts to Hawaii bigeye community, some worry that it could set back global efforts towards sustainable management of the fishery. This study highlights the challenges and equity considerations inherent in efforts to achieve meaningful conservation benefits from localized management actions within a global fishery. It also demonstrates the importance of interdisciplinary socioeconomic monitoring to examine how global fisheries policies scale down to individual fishing communities.

van der Hammen, T., de Graaf, M., & Lyle, J. M. (2016). Estimating Catches of Marine and Freshwater Recreational Fisheries in the Netherlands Using an Online Panel Survey. *ICES Journal of Marine Science*, 73(2), 441-450. <https://doi.org/10.1093/icesjms/fsv190>

In this study we describe a two-phase survey design and implications of approaches to non-response adjustments on estimates of the total catch taken by Dutch recreational fishers, including marine catches for Atlantic cod and European seabass and European eel in freshwater. The survey comprised three main elements which were executed online: a screening survey to estimate the characteristics of the population of recreational fishers (number of fishers, their demographic profile and stated fishing avidity); a 12 month logbook survey to estimate effort and catch rates; and non-response follow up surveys to adjust for non-response. A response rate of 80% was achieved for the screening survey and, following non-response adjustment and limited data imputation, 89% for the logbook survey. Some logbook participants reported no fishing activity (drop-outs) and were removed from the analysis. In addition, logbook data were weighted in accordance with the stated avidity distribution in the population to address potential response bias based on avidity. Imputation and weighting for avidity influenced the catch estimates a little, whereas the removal of the fisher drop-outs was influential, linked to the rates of fisher drop-outs (18% for freshwater and 55% for marine fishers). Freshwater recreational fishing was more popular than marine fishing; 9.7% of the Dutch population participating in the former and 4.1% fishing in marine waters. In total an estimated 53.6 million freshwater fish were caught (2.6 million retained) and 13.6 million marine fish were caught (9.6 million retained). Respective catch estimates for Atlantic cod, European seabass and European eel were 0.70, 0.35 and 1.23 million fish (0.53, 0.23 and 0.34 million retained). We conclude that the survey design using an online panel may

serve as an example for future surveys because of its efficacy to collect a rich set of data at relatively low cost compared to traditional survey methods.

Venturelli, P. A., Hyder, K., & Skov, C. (2017). Angler Apps as a Source of Recreational Fisheries Data: Opportunities, Challenges and Proposed Standards. *Fish and Fisheries*, 18(3), 578-595.
<https://doi.org/10.1111/faf.12189>

Recreational fisheries surveys are limited in time and place in many countries. This lack of data limits scientific understanding and sustainable management. Smartphone applications (apps) allow anglers to record the details of their fishing trips and catches. In this study, we describe the opportunities and challenges associated with angler apps as a source of recreational fisheries data, and propose minimum standards for data collection via angler apps. Angler apps are a potentially valuable source of conventional and novel data that are both frequent and extensive, and an opportunity to engage anglers through data sharing and citizen science. Realizing this potential requires that we address significant challenges related to angler recruitment and retention, data quality and bias, and integration with existing fisheries programmes. We propose solutions to each of these challenges. Given that the angler app market is diverse, competitive and unpredictable, we emphasize minimum standards for data collection as a way to ensure large and reliable data sets that can be compared and integrated across apps. These standards relate to trips and catches, and angler demographics and behaviour, and should be supported through consultation and research. Angler apps have the potential to fundamentally change how anglers interact with the resource and with management.

Section VII: CPUE

Barua, S., Magnusson, A., & Humayun, N. M. (2018). Assessment of Offshore Shrimp Stocks of Bangladesh Based on Commercial Shrimp Trawl Logbook Data. *Indian Journal of Fisheries*, 65(1), 1-6. <https://doi.org/10.21077/ijf.2018.65.1.61384-01>

This study presents the results of analytical assessment of offshore shrimp stock in Bangladesh marine waters. A time series of annual catch per unit effort (CPUE) was derived from commercial logbook data during the period from 1986 to 2016 and used as a turning series for a Schaefer biomass model. The current stock size and annual harvest rate were estimated to be around 20300 t and 20% respectively, with the stock size increasing in the last ten years. The estimated maximum sustainable yield (MSY) reference points with 95% confidence intervals are optimal biomass $B_{MSY} = 15800$ t (11300-22000 t) and optimal harvest rate $u(MSY) = 30\%$ (21-42%). The average annual catch was 4650 t, close to the estimated MSY of 4710 t (4570-4860 t). Overall, the stock is estimated to be in a good state and the data show that CPUE in recent years is slightly above the long-term average. The assessment results are subject to considerable uncertainty, reflected in wide confidence intervals around the estimated stock status. Moreover, the simple assessment model has restrictive assumptions that may not capture the underlying dynamics of the Bangladesh shrimp fishery, a multispecies tropical fishery with changes in the fleet composition and fishing technology. Nevertheless, the model fits well to the CPUE data and the assessment is a valuable basis for giving short-term and long-term management advice.

Ducharme-Barth, N. D., Shertzer, K. W., & Ahrens, R. N. M. (2018). Indices of Abundance in the Gulf of Mexico Reef Fish Complex: A Comparative Approach Using Spatial Data from Vessel Monitoring Systems. *Fisheries Research*, 198, 1-13. <https://doi.org/10.1016/j.fishres.2017.10.020>

The Gulf of Mexico reef fish complex is socioeconomically important and is exploited by a vertical line fishery capable of high resolution spatial targeting. Indices of abundance derived from fishery dependent catch-per-unit effort (CPUE) data are an important input to the assessment of these stocks. Traditionally, these indices have been derived from standardized logbook data, aggregated at a coarse spatial scale, and are limited to generating predictions for observed spatiotemporal strata. Understanding how CPUE is spatially distributed, however, can help identify range contractions and avoid hyperstability or hyperdepletion, both of which can mask the true population dynamics. Vessel monitoring systems (VMS) can provide complete, high-resolution distributions of CPUE used to create abundance indices. Here we compare two methods - spatial averaging of VMS-derived catch and effort data and the result of generalized linear models applied to logbook data for generating indices, to evaluate the use of VMS-derived abundance indices in assessments of reef fish stocks. This work suggests that in fisheries where targeting occurs at very fine spatial scales, abundance indices derived from high-resolution, spatiotemporally complete data may more accurately reflect the underlying dynamics of the stock.

Maunder, M. N., Sibert, J. R., Fonteneau, A., Hampton, J., Kleiber, P., & Harley, S. J. (2006). Interpreting Catch Per Unit Effort Data to Assess the Status of Individual Stocks and Communities. *ICES Journal of Marine Science*, 63(8), 1373-1385. <https://doi.org/10.1016/j.icesjms.2006.05.008>

Despite being one of the most common pieces of information used in assessing the status of fish stocks, relative abundance indices based on catch per unit effort (cpue) data are notoriously problematic. Raw cpue is seldom proportional to abundance over a whole exploitation history and an entire geographic range, because numerous factors affect catch rates. One of the most commonly applied fisheries analyses is standardization of cpue data to remove the effect of factors that bias cpue as an index of abundance. Even if cpue is standardized appropriately, the resulting index of relative abundance, in isolation, provides limited information for management advice or about the effect of fishing. In addition, cpue data generally cannot provide information needed to assess and manage communities or ecosystems. We discuss some of the problems associated with the use of cpue data and some methods to assess and provide management advice about fish populations that can help overcome these problems, including integrated stock assessment models, management strategy evaluation, and adaptive management. We also discuss the inappropriateness of using cpue data to evaluate the status of communities. We use tuna stocks in the Pacific Ocean as examples.

Quirijns, F. J., Poos, J. J., & Rijnsdorp, A. D. (2008). Standardizing Commercial CPUE Data in Monitoring Stock Dynamics: Accounting for Targeting Behaviour in Mixed Fisheries. *Fisheries Research*, 89(1), 1-8. <https://doi.org/10.1016/j.fishres.2007.08.016>

Catch per unit effort (CPUE) is commonly used as an indicator for monitoring developments in stock size. To ensure proportionality between average CPUE and total stock size, two processes that should be accounted for are the degree of targeting behaviour of the fleet and the management-induced responses in fishing behaviour. We studied the effect of restrictive individual quotas and targeting

behaviour on average CPUE in the Dutch beam trawl fleet. Fishing opportunities varied in time and across species due to changes in quotas. Using catch and effort data by fishing trip of the total fleet and haul-by-haul data from a reference fleet, targeting behaviour of the beam trawl fleet was quantified for sole and plaice, at various space and time scales. Sole was targeted on all scales examined, whereas plaice was only targeted on a micro-scale of 10 x 10 nautical miles. When sole quota restrictions were relaxed, the fleet increasingly targeted sole instead of plaice. Targeting indices for sole and plaice were negatively correlated. Our findings indicate that catch and effort data by fishing trip are sufficient to characterise targeting behaviour on a macro-scale, whereas haul-by-haul data are needed to quantify the targeting on a micro-scale (30 x 30 nautical miles). The micro-scale targeting index can be used to standardize macro-scale CPUE data for bias due to variations in directed fishing among local fishing grounds.

Schroeter, S. C., Reed, D. C., Kushner, D. J., Estes, J. A., & Ono, D. S. (2001). The Use of Marine Reserves in Evaluating the Dive Fishery for the Warty Sea Cucumber (*Parastichopus parvimensis*) in California, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(9), 1773-1781.
<https://doi.org/10.1139/cjfas-58-9-1773>

Management of sustainable fisheries depends upon reliable estimates of stock assessment. Assessment of many stocks is based entirely on fishery-dependent data (e.g., catch per unit effort), which can be problematic. Here we use fishery-independent data on stock size, collected within and outside of no-take reserves before and after the onset of fishing, to evaluate the status of the dive fishery for warty sea cucumbers, *Parastichopus parvimensis*, in southern California. Long-term monitoring data showed that abundance decreased throughout the Channel Islands within 3-6 years after the onset of fishing. No significant changes in the abundance of *P. parvimensis* were observed at the two non-fished reserve sites, although densities tended to increase following onset of the fishery. Before-after, control-impact (BACI) analyses of seven fished and two non-fished sites implicated fishing mortality as the cause of 33-83% stock declines. In sharp contrast, stock assessment based on CPUE data showed no declines and a significant increase at one island. To date, most discussion on marine reserves has focused on the protection and enhancement of exploited populations. Our study demonstrates the critically important, but often overlooked, role that marine reserves can play in providing reliable information on stock assessment.

Williams, A. J., Ballagh, A. C., Begg, G. A., Murchie, C. D., & Currey, L. M. (2008). Harvest Patterns and Effort Dynamics of Indigenous and Non-Indigenous Commercial Sectors of the Eastern Torres Strait Reef Line Fishery. *Continental Shelf Research*, 28(16), 2117-2128.
<https://doi.org/10.1016/j.csr.2008.03.030>

The reef line fishery (RLF) in eastern Torres Strait (ETS) is unique in that it has both a commercial indigenous sector and a commercial non-indigenous sector. Recently, concerns have been expressed by all stakeholders about the long-term sustainability of the fishery. These concerns have been exacerbated by the lack of detailed catch and effort information from both sectors, which has precluded any formal assessment of the fishery. In this paper, we characterise the harvest patterns and effort dynamics of the indigenous and non-indigenous commercial sectors of the ETS RLF using a range of data sources including commercial logbooks, community freezer records, voluntary logbooks and observer surveys. We demonstrate that bycatch is a significant component of the catch for both sectors and identify substantial differences in harvest patterns and effort dynamics between the sectors. Differences

between sectors were observed in species composition and spatial and temporal patterns in catch, effort and catch per unit effort. These results highlight the inherent variation in catch and effort dynamics between the two commercial sectors of the ETS RLF and provide valuable information for the development of future assessments and appropriate management strategies for the fishery. The more reliable estimates of harvest patterns and effort dynamics for both sectors obtained from observer surveys will also assist in resolving issues relating to allocation of reef fish resources in Torres Strait.