Abstracts of the Joint 10th FSU-Mote International Symposium on Fisheries Ecology & 6th International Symposium on Stock Enhancement and Sea Ranching

Oral presentations

Plenary

Applying Fundamental Ecological Concepts to Fisheries-Enhancement Science

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Consideration of fisheries habitat availability and quality should be a central component of fisheries stock enhancement programs. Habitat carrying capacity can drive recruitment success of stocked organisms, and population bottlenecks due to some form of habitat limitation can lead to unsuccessful stocking attempts. Identification of when and where to enhance habitat and fishery stocks can be guided by similar ecological concepts. Concepts such as metapopulation and source/sink dynamics can guide quantification of population connectivity and spatiotemporal variation in demographics rates of target species. This ecological information can then feed into Geospatial Habitat Suitability Index (HSI) models that can also integrate other external drivers such as land use, socio-economic factors, and environmental characteristics. HSI models have emerged as powerful tools that integrate pertinent spatial information to guide habitat restoration efforts, and can also account for spatial variation in ecosystem service provision. We highlight an ongoing oyster restoration program in North Carolina, USA as an example of integrating metapopulation and source/sink dynamics with an HSI modeling framework being used to guide restoration by the state's habitat enhancement division. Fisheries stock enhancement programs can be used to test predictions from models. In the future, stock enhancement may be a component of a more general environmental intervention aimed at improving habitat "quality", as well as generating data on ecosystem services that can be monetized to further justify fisheries and habitat enhancement.

Trends in research on marine release programs (aquaculture-based enhancement) in western countries compared with China and Japan

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Scientific literature on marine release programs between 2000 and 2018 was systematically reviewed to evaluate the current state of aquaculture-based-enhancement (ABE = restocking, stock enhancement and sea ranching) for commercial and recreational fisheries in North America, Europe, Oceania and southern Asia. Comparisons are made with a recent review of the effectiveness of marine release programs (Kitada, 2018) and reviews and government information on ABE in China and Japan, where large-scale continuous releases have been practised for over three decades. Six broad categories of release programs were identified: (1) Enhancement to increase commercial yield and value; (2) Restocking to increase the spawning population of a commercial or recreational fishery; (3) Restocking species to avoid extinction (4) Conservation restocking of species within protected areas; (5) Sea ranching – creating or maintaining a fishery by releasing individuals and harvesting them before they mature; and (6) Releasing individuals to increase knowledge of the species and ABE systems. Teleosts, crustaceans, molluscs and echinoderms were the focus of most publications in North America, Europe, Oceania and south Asia. This contrasts with China where there is a major focus on commercial releases of invertebrates, particularly penaeid prawns. In the other regions considered in the review, releases have been of a much smaller scale (generally 10,000s to 1,000,000s) than in China and Japan, and focus largely on species of recreational significance (= leisure fisheries) e.g. penaeid prawns (*Penaeus plebejus*, *Metapenaeus dalli*), and Mulloway (*Argyrrosomus japonicas*) in Australia and Blue Crab (*Callinectes sapidus*) Red Drum (*Sciaenops ocellatus*) and Snook (*Centropomus undecimalis*) in the United States. This focus on recreational ABE requires information on the values and perceptions of these fishers and highlights the need to understand the social dimensions of recreational marine release programs and the need for rigorous evaluation of the costs and benefits of such programs. Kitada, S. (2018). Economic, ecological and genetic impacts of marine stock enhancement and sea ranching: A systematic review. Fish and Fisheries 19: 511 – 532.

Science considerations in restoring, sustaining, and enhancing marine fisheries

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Enhancing fisheries productivity can involve the use of habitat-based strategies as well as aquaculture technologies. Such approaches in increasing fisheries productivity must strive to be effective, economically and ecologically sustainable, and socially acceptable. At the same time, the impacts of present-day significant and rapidly changing environmental and ecosystem-level conditions must be considered, with explicit adaptation plans. Aspects of the scientific basis for fisheries enhancement strategies will be highlighted, and steps in the integration of science-based approaches discussed.

Theme f. Commercial-scale enhancement: Successes, failures and impediments

Enhancement of New Zealand's commercial paua (abalone) fishery: What have we learned and where are we going?

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New Zealand has one of the largest remaining wild abalone (known locally as paua) fisheries in the world, with an annual catch of approximately 700t. While stocks are generally stable, declines in some areas, and increasing concerns about environmental impacts on the fishery over the last two decades have seen the development of stock enhancement (reseeding) programs. For paua, stock enhancement generally involves rearing juveniles in the hatchery to approximately 10mm, and releasing them into habitats to supplement natural recruitment in areas that are locally depleted. Over the last 20 years, enhancement programs have consisted of a number of small-scale industry-based initiatives around different regions of the country, as well as several research programs aimed at determining the optimum methods for enhancement and determining overall viability. This has lead to the development of recognised practices for best seed sizes, densities, methods for deployment and targeted habitats. Most recently, reseeding has been implemented to assist the recovery of paua stocks that were severely affected by the 2016 Kaikoura earthquake. Despite surveys that have shown positive effects of reseeding on paua biomass, as well as modelled economic return on investment of 20%, there is still a limited appetite to pursue enhancement on larger scales. The main reason for this is that programs are all largely industry-funded, and there is lack of confidence amongst stakeholders that reseeding has tangible positive outcomes for the fishery, especially when compared to the opportunity cost of implementing other management tools.

TURF based abalone stock restoration using hatchery spat and private security protection in the Eastern Cape, South Africa.

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Fishery management control over the South African perlemoen abalone (*Haliotis midae*) fishery has largely been lost with most of the harvest being illegally caught. A strategy to restore stocks and a legal harvest regime is abalone ranching and stock enhancement which is being tested by the South African fisheries authority in partnership with participating abalone farms and other stakeholders. We report on our research in support of commercial abalone ranching project at a heavily poached location at Cape Recife, Port Elizabeth. Prior to the initiation of the project, abalone numbers had declined from 1.6 abalone per m2 in 1993 to 0.1 abalone per m2 by 2013. Since 2014, the area has been protected by private security and over 3 million hatchery reared abalone seeded. In addition, recruitment has been monitored in the shallows with densities of abalone less than 60mm SL ranging between 0.6 and 6.35 abalone m-2. A research survey conducted in January 2018 indicated that on commercially seeded sites the average density increased from 0.3 abalone per m2 in 2014 to 3.3 abalone per m2 in 2017, while on unseeded plots the average density had increased to 0.9 abalone per m2 in January 2018. Results also indicate that the hatchery seed contributed more than 50% of the abalone found on sites. It is clear that while there is no clear indication of the proportional contribution of natural and hatchery recruitment, the combination of protection coupled with seeding

hatchery reared spat is resulting in stock recovery. Key to the success of the project is the TURF (Territorial User Rights Fishery) system which incentivizes private sector investment in stock rebuilding by means of exclusive and secure long-term rights. The success of the model has profound implications for the management and restoration of abalone resources in South Africa.

Model selection to improve abundance estimates for the South African abalone and inform stock management decisions for the ranching and reseeding program.

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The South African perlemoen abalone fishery is a valuable commercial fishery that has declined due illegal fishing, mismanagement and changes in the ecosystem. In an attempt to restore the fishery, a commercial scale ranching and reseeding program was established in 2014 which the allows rights holder to release abalone onto local natural reef systems in Port Elizabeth, Eastern Cape. The rights holder are further required to protect and monitor the stocks. This has led to increases in abundance estimates for abalone in the area and has been created the need for a stock assessment in order to determine the status of the stock and what it could potentially yield. The present research was evaluated different models to determine the best fit for estimation of maximum likelihood estimates for abalone abundance. We tested and compared four models, including a Generalized Linear Models (GLM) with a Poisson distribution, a GLM with a Negative Binomial distribution, a Zero-Inflated Generalized Linear Mixed Models (GLMM) with a Poisson distribution (ZIP), and a Zero-Inflated Negative Binomial distribution (ZINB). Model selection was preformed using Akaike's information criteria (AIC). Markov chain Monte Carlo (MCMC) simulations were used to generate a samples from the posterior distribution. Additionally, a Beverton-Holt yield per recruit model was developed in order to determine the maximum sustainable yield (Fmsy) of the resource with the assumptions of natural recruitment being constant, as well as ranching and seeding providing additional economic recruitment. The aforementioned parameters were then used to simulate five different scenarios which including re-seeding with antipoaching and no future harvesting on the resource, re-seeding with antipoaching and a future harvesting on the resource set at a 35% depletion threshold, no re-seeding but antipoaching and a future harvest with a 35% depletion threshold, antipoaching but no re-seeding or future harvesting on the resource, and lastly a scenario of no harvesting, reseeding or antipoaching with poaching at historical rate. The results of this study are being used to inform both the rights holders and management authorities in order to ensure sustainable yields and productivity of the abalone population.

Scallop (*Pecten maximus*) sea-ranching in Norway – lessons learned

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The development of sea-ranching in Norway has been based on intensive hatchery and nursery culture, followed by intermediate culture at sea to produce spat for releases on to the seabed for growth to market size. The initial experimental releases on to the seabed experienced high and unacceptable level of crab (*Cancer pagurus*) predation and propelled the development of fences on the seabed to prevent crab access to the sea- ranched scallops. Different types of fence were tested by farmers, and a flexible, cost-efficient fence was eventually used for up-scaling production at two

sea-ranching sites in south- western Norway. The structure of the sea-ranching industry development changed from many farmers trialing scallop culture to an up-scaling phase with two companies partly integrated with the spat supplier and with an overall stronger financial situation from investors. These companies developed the sea- ranching operations on intermediate culture technology, cost efficiency of husbandry operations, predator control involving fishing of crabs and sea stars, product marketing, evaluation of site suitability, etc., while government-based research assessed the benthic environmental impact related to possible attractions and exclusion due to the fenced scallops. However, the commercialization of scallop sea-ranching failed, mainly due to factors like slower growth than expected, sub-optimal sites, and weakened interest from investors and governmental support. Nevertheless, the concept of combining released scallops from hatchery production and transferred scallops caught in the diver-based fishery to a sea-ranching area has been commercially applied for several years. The transferred fished scallops are sucessfully supporting consistent supply to the market, while the survival of the aquaculture scallops is still unknown. Concerns about the potential genetic and ecological impact of releasing hatchery-produced scallop spat will be discussed and examples of challenges that companies have met with local authorities when applying for sea-ranching areas will be given.

Theme e. Fisheries enhancement in support of recreational fisheries

Untapped potential of spatially explicit stock enhancement to improve management and learning in recreational fisheries socioecological systems

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Stock enhancement has long been used to manage recreational fisheries. Today, stocking is still commonly employed to increase fishing effort and associated economic effects, bolster catch rates related to angler satisfaction, and hopefully augment rather than detract from wild fish populations. However, simultaneously achieving these objectives is challenging. Biological interactions between stocked and wild fish, coupled with socioecological interactions between fish and fishers can result in trade-offs that decrease stocking efficacy. However, these same trade-offs reveal opportunities for spatially explicit stocking applications. While almost all stocking has some inherent spatially explicit component, evaluations and strategic applications of spatial stocking are not common and may represent a missed opportunity for improving management and scientific understanding. I first describe how strategic, spatially explicit stocking across a diverse socioecological landscape may allow for seemingly conflicting objectives to be simultaneously augmented at a regional scale. Further, this approach may better satisfy angler populations increasingly understood as diverse with respect to motivations for and satisfaction achieved from fishing. I also describe a novel, "minimalist" stocking approach potentially useful in cases that stakeholder stocking preferences have decoupled from biological stocking outcomes. I continue to describe how spatially explicit stocking may be strategically designed to address two broader challenges to natural resource management. First, spatially explicit stocking is particularly compatible with cooperative management paradigms that directly involve stakeholders in management decisions. Directly involving anglers in decisions like what fish to stock in which areas may lead to overall greater stakeholder investment and involvement with management. Second, spatially explicit stocking can be strategically designed to increase learning about socioecological systems via active adaptive management. Common characteristics of stocking programs—namely repeated annual additions of fish to multiple waters—provide the exact experimental contrast and replication so critical for "learning by doing". Learning can include not only ecological relationships, like recruitment dynamics, but also socioecological linkages (e.g., angler effort responses, effects of agency communication). I conclude by suggesting both research needs and practical agency actions that may facilitate making the most of existing and new stock enhancement programs in recreational fisheries.

Stocking Spatial Planning: Addressing Socioeconomic and Conservation Trade-offs in Recreational Fisheries Systems and a Landscape Scale

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Recreational fisheries are typified by two common management objectives—conserving wild fish populations and providing angler satisfaction. Trade-offs between these objectives commonly exist in

the short-run. Stock enhancement has been historically proposed to circumvent these trade-offs, but recent research suggests this is unlikely at the water-body scale. Here we consider if spatially explicit stocking might work better, and increase both conservation and socioeconomic objectives at a landscape scale. To address this, we employ a socioecological simulation model representing a heterogeneous landscape, as well as key fish population dynamics, angler behaviors, and management decisions. We find that at a landscape scale, win-win approaches to conservation-socioeconomic trade-offs are possible with stock enhancement, but only under specific conditions of wild recruitment, angler movement, and stocking strategy. Embedding this model in a management strategy evaluation showed that positive outcomes also required specific criteria for deciding which waters were stocked, and that detecting these improvements would be challenging with variable wild fish recruitment. All results were particularly sensitive to societal valuations of wild versus hatchery fish. This work promotes increased incorporation of spatial planning into the management of recreational fisheries where multiple social or conservation objectives are likely to occur.

Enhancing recreational crustacean fisheries in south-east Australian estuaries

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Aquaculture-based fisheries enhancement involves the rearing and release of fish to achieve specific fisheries outcomes. Over 1 million people fish for leisure in south-eastern Australian waters every year, and aquaculture-based fisheries enhancement is one of several government-led strategies aimed at improvement of fishing experience for anglers. Several release programs and an associated regulatory framework have been developed over the past decade, with the primary objective of enhancing recreational fisheries for species spanning penaeid prawns, crabs, and finfish. One of the most unique and successful programs within this strategy has been the enhancement of recreational prawn fisheries. We present a description of recreational prawn fisheries in NSW, followed by a synopsis of the research, development and outcomes of the NSW Eastern King Prawn (*Penaeus plebejus*) from inception to implementation of an ongoing program. We highlight factors that have contributed to the success of this program, including ecosystem and fisheries attributes that underpin positive outcomes, as well as lessons learnt and some of the challenges that have hampered continued enhancement efforts (such as disease, genetics, contamination and broodstock management). We also present our management and evaluation approaches, and highlight how these support this program within the overall enhancement strategy.

Marine Fisheries Replenishment in Southern California – A Status Report

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The Ocean Resources Enhancement and Hatchery Program (OREHP) in Southern California completed a comprehensive three year external Program review in 2018 followed by a series of stakeholder surveys. The review was coordinated by California Sea Grant under contract from the California Department of Fish and Wildlife (DFW). A 10-member Science Advisory Committee (SAC), representing specific areas of relevant expertise (e.g. genetics, sciaenid biology, fish health, etc.), was recruited to conduct the evaluation. This was the first formal evaluation in the Program's 35 year history. The Evaluation generated over 100 recommendations and concluded that "OREHP has met the original intent of the California State Legislature to conduct basic and applied research on the

propagation, rearing, stocking, and distribution of an important marine fish, White Seabass." However, mark-recapture data has shown that hatchery fish make up less than 1% of the adult stock. An analyses conducted within the review suggested that if short term post-release mortality in hatchery fish could be improved to match that of wild fish, the contribution to the adult stock could be as high as 18% without needing to release more fish. Since the Evaluation concluded, The OREHP Advisory Panel (AP) has been working with the DFW to plan out the next steps for the Program. This includes seeking additional funding because inadequate funding was highlighted in the Evaluation as a major constraint to successfully meeting Program objectives. There is a strong consensus among the AP, as well as most stakeholders, to continue seabass enhancement research for a finite period to answer some outstanding questions and to see if post-release survival can be improved. Additionally, there is a desire to strengthen the Program's oversight structure through a variety of means, including adding a Science Advisory Committee to complement the existing AP. While research on secondary species to white seabass (i.e. California halibut) was put on hold decades ago due to funding constraints, the Evaluation has rejuvenated these discussions and it appears that California halibut has remained at the top of the list amongst fishery managers and recreational anglers. HSWRI has recently re-established a small scale culture program for halibut that is privately funded and currently operated separately from the OREHP. Pilot scale releases are already planned for 2019 pending release authorization from the DFW.

Population modeling and assessment of a White Seabass stock enhancement program in California, USA

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A stock enhancement program for White Seabass of Southern California was established in 1983 and has released an average of over 100,000 hatchery-reared juveniles per year. Over the same period, the white seabass population increased substantially due to reduced commercial fishing pressure and an episode of strong natural recruitment. Released hatchery fish accounted for only 0.26% of catches on average throughout this period. We used a population dynamics model, informed by mark-recapture analyses of released hatchery fish and a quantitative stock assessment of the wild seabass stock, to explore reasons for the low hatchery contribution and potential options for enhancing the impact of the program. High post-release mortality of hatchery fish was found to be the main reason for low hatchery contributions to the fishery. If mortality of released hatchery fish could be reduced to levels similar to those experienced by wild White Seabass, current stocking rates result in an 18% contribution to catches. It appears likely that post-release mortality can be reduced through judicious changes in rearing and release methods, though it is not known whether improvements would be large enough to increase to contribution of the program substantially. The observed and modeled effect of current releases was small but additive, i.d. stocked fish added to overall abundance and did not replace wild fish, most likely owing to the large size at which hatchery fish were stocked. We conclude with a discussion of options for, and potential management implications of modifications that could enhance the impact of the hatchery program on the White Seabass fishery.

Theme a. Developments in the science base of aquaculture-based enhancement: biology, ecology, and genetics

Can we produce “better” fish? How rearing environments affect behaviors, brains, and post-stocking performance

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When stocking fish for population enhancement- and conservation purposes, the aim is to stock individuals that display a natural behavior and have a high survival capacity in the wild. That is, we want wild-like fish. However, for at least a century, fisheries managers and researchers have noted that the post-stocking performance of hatchery reared fish deviates from the performance of wild conspecifics. In many cases, hatchery reared fish have lower survivability and display behaviors that are potentially maladaptive in natural environments. In my talk, I will provide a picture of the current state of knowledge about how we could possibly change the hatchery environment to alleviate some of the negative effects of artificial rearing. Specifically, I will talk about structural in-tank enrichment and fish density reductions, and how these environmental alterations change the behavior, brain growth, and general post-stocking performance of hatchery-reared fish. Particular emphasis will be put on empirical studies of salmonids in northern Europe. The presentation will also put these results in a wider geographical and taxonomical perspective. From a methodological perspective, I will also discuss potential improvements in experimental designs and present my view of the current knowledge gaps in this field of research.

Domestication of abalone: what consequences for *Haliotis tuberculata* behaviour, physiology and growth after one generation of selection

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Domestication of *Haliotis tuberculata* began recently. During the process, abalone behavioural, morphological and physiological traits may evolve resulting from intentional selection of production traits, or unconscious and unintentional selection due to farm environment. Progeny of wild parents, selected farmed parents and randomly sampled farmed parents were studied to evaluate this process. Farmed abalone were the third generation of abalone resulting from systematic mating between wild and farmed broodstock, without intentional selection. After 16 month rearing in separate tanks, offspring from the 3 progenies were individually tagged and placed together in sea-cages at the same density. After 3 years, behaviour traits (circadian rhythm, righting, predator and hiding behaviour) were studied and immune status after a stress was assessed. Mortality and growth were also recorded. No significant differences were observed for survival, growth or immune status traits between the 3

progenies. However, more progeny from the selected broodstock did not perform the complete sequence of anti-predation behaviour, and took more time to reach their hides compared to the wild progeny. In addition, the shell colours of the selected progeny had more stripes and were more orange compared to the brown-green colour of the wild progeny. Progeny of randomly sampled broodstock had intermediate responses between wild and selected ones. Our results indicate that conscious selection can modify the behaviour and shell color of abalone undergoing a domestication process in only one generation. The degree of domestication of farm animals is likely to affect their fitness in the context of ranching or population-enhancement operations.

Genetic monitoring contributes to preserve local genetic diversity and the adaptive potential of translocated wrasses, and insights into the threat of climate change

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Marine enhancement initiatives have proven very useful for conservation and sustainable management of some fishery resources worldwide. Preserving the local genetic diversity is crucial to safeguard the adaptive potential of hatchery-released juveniles to the local conditions and ensure population resilience. Yet, only a few programs have taken advantage of existing genetic tools to improve our understanding of adaptive fitness of hatchery-releases and translocations of marine organisms. Here, I will present the results of several experimental studies using DNA- and RNA-based approaches conducted on corkwing wrasse (*Symphodus melops*) in Norway. Parentage assignment genotyping 11 microsatellite DNA markers revealed significant differences in parental contribution and in the proportion of local vs translocated breeders contributing to the total 1243 offspring collected at two time intervals (pre- and post-wintering). Later on, their offspring were exposed to three different temperature conditions resembling those encountered in a latitudinal gradient along the Norwegian coast as well as under a projected global warming scenario. The RNA analysis revealed that temperature has a major effect on gene expression profiles of corkwing wrasse offspring. However, all three offspring groups displayed similar responses, regardless their parental origin. These results highlight the importance of monitoring the genetic inheritance at the right time in order to minimize the risk of inbreeding and safeguard the genetic diversity of local stocks. Current findings also suggest no differences in adaptive fitness between offspring of local and non-local parental origin. On the other hand, the raise in sea water temperature projected over the next decades may compromise the adaptive response of both local and translocated offspring, an important consideration for fisheries management. This experience insight into the potential benefits of incorporating genetic and genomic approaches into marine stock enhancement and translocations programs to minimize any putative genetic risk and improve management practices.

Experimental methodologies optimized for examining the scope of responses in early life-stages of marine fishes in wild or captive populations due to multiple stressors and variable environments.

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Studies of biological effects of fish early life-stages (ELS) to variable environments, including captive conditions as well as those in the wild associated with a changing climate, will benefit by progressions from descriptive to predictive, and from qualitative to quantitative characterizations of these environmentally induced biotic responses. We describe experimental systems for generating broad-spectrum, high-treatment frequency, and variable environmental factors useful for characterizing biotic plasticity by small-bodied marine organisms. The first apparatus is a thermal gradient block that can generate several dozen different constant thermal regimes for evaluating temperature effects on key ELS responses. The second apparatus uses a novel means of generating a large number of CO2 environments useful for studying ELS responses to future ocean acidification. The third apparatus, analogous to the CO2 one, provides a large number of different dissolve oxygen environments. All systems can simulate high-frequency temporal variability (e.g., daily, tidal). All have been tested using ELS responses of the estuarine forage fish Atlantic silverside (*Menidia menidia*) and of the commercially important summer flounder (*Paralichthys dentatus*). Regarding thermal regimes, embryonic period duration (EPD) decreased as a power function with warming temperature, size at hatch decreased consistently with warming temperatures, and survival to hatch decreased at temperature extremes. Elevated CO2 resulted in decreased EPD, hatch size was maximal at intermediate CO2 levels, and both survival and hatch size decreased with increasing variability in CO2. Lower DO resulted in lower survival, longer EDP, and hatching at smaller sizes; a pattern that was apparent when hypoxia was combined with other stressors (e.g., increasing CO2). Importantly, accurately characterizing these biological responses is beyond the reach of experimental designs with few treatment levels and, in many cases, the shapes of the biological responses would not be unmasked in such low treatment-level designs.

Naïve European lobster released for stocking purposes – will they stay, or will they go; results from a small-scale study in Bjørnafjorden, southwestern Norway

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As a part of increasing our understanding of the dynamics related to restocking European lobster (*Homarus gammarus*), the aim of this study was to elucidate the movement pattern in newly released naïve European lobster (i.e. hatchery-produced) and compare with wild lobster in a locality situated in western Norway, Bjørnafjorden. A total of 45 individuals (10 naïve, 35 wild) were tagged with acoustic tags (VEMCO V9 or V13) and streamers (Hallprint ltd.). The acoustic tag was attached to one of the claws and would be lost at next moult. Ten receiver moorings, spaced at 50 to 200 m, was deployed in the area. The wild lobster was captured, tagged and released the same day. The naïve lobsters were also tagged and released at the same time. The size ranged from 47 to 59 mm carapace length in naïve (3 females and 7 males) and from 63-101 mm in wild lobster (23 females and 12 males). Seven of the wild females were ovigerous. The acoustic experiment started 5 December 2016 and ended 20 June 2017. Seven of the naïve lobsters and two of the wild did not move either due to tag loss or due to mortality (F or M). Of the three remaining naïve lobsters, one female was very stationary while two males moved around in the area. Among the wild lobsters, 30 individuals were characterized as stationary and stayed within a narrow home range. However, the activity within the home range was relatively high for some of them. All of the ovigerious wild females were stationary, one moved to the deepest part and moved to shallower ground during spring. A total of 16 wild lobsters (9 females and 4 males) were recaptured in the commercial fishery in 2017-2018. Of these, two (1 female and 1 male) had moved considerably distances. One female had moved up to 8 km from the original site. Due to the high mortality of naïve lobster it is difficult to conclude whether they “stay or go”. However, the few data we collected indicate that activity pattern in naïve lobster is comparable to wild lobster. This study also confirms previous findings that naïve lobster released for stocking purposes suffers high mortality shortly after release.

Using Individual-Based Models to Determine Optimal Harvest Reduction and Stock Enhancement to Minimize Genetic Impacts during Restoration of Wild Cobia Populations

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Cobia is a coastal migratory pelagic species that is targeted by the recreational fishery along the Atlantic coast of the Southeastern United States and in the Gulf of Mexico. We have determined through genetic analyses that cobia are made up of several stocks as well as genetically distinct population segments. One such distinct population segment forms an annual inshore spawning aggregation in South Carolina and because of its proximity to shore has been severely overfished. Concerns over the status of the inshore cobia population in SC have been raised by a diverse group of stakeholders, including state resource managers, recreational fishermen, and charter boat captains. The combined evidence for declining abundance has required conservation action, including both changes in regulations and supportive stocking, however little information is available to guide the relative roles of stock enhancement and harvest reductions to facilitate recovery of this population. From a genetic perspective, care is needed to ensure that recovery efforts maintain both genetic diversity and effective population size, as both are important for the long-term adaptability of the population. An individual-based model was developed to identify the best responsible conservation and restoration strategies for SC's inshore cobia population. The model incorporates results of pilot-scale stocking outcomes, genetic data, and demographic information derived from stock assessments and generates output that provides a range of possible management alternatives using both harvest reduction and stock enhancement strategies. The incorporation of quantitative predictions derived from the model to guide comprehensive restoration activities constitutes important guidance for fishery managers interested in application of a broad set of management tools.

Timely Estimation of Post-release Survival for Hatchery-reared Juvenile Fishes

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Effective adaptive management of stock enhancement programs requires that the impact of stocking activities be understood in a timely fashion. For estuarine and marine finfishes, post-release survival has been particularly challenging to measure. We apply novel principles for release activities of hatchery-reared juvenile common snook (*Centropomus undecimalis*) in southwest Florida to guide timely estimation of post-release survival. Following a replicate release design for two experimental releases, 1,920 juvenile snook marked with passive integrated transponder (PIT) tags were released among four locations in two regions of Phillippi Creek. Marine-adapted PIT tag antenna arrays monitored the release sites and provided recapture histories that were analyzed at three month intervals with Cormack-Jolly-Seber mark-recapture models. Patterns in post-release relative survival and detectability were consistently identified after one year of monitoring. Recapture histories were best explained by short-term differences in survival among the first four weeks after release, and long-term patterns in detectability among release sites. Yet, these patterns differed among seasons, particularly for short-term survival. The highest survival rates were observed for individuals released in the lower reaches of the tidal creek systems in the spring, indicating these areas may provide ideal release sites for juvenile fishes at that time. Identifying optimal release sites and times will promote adaptive management of stock enhancement programs and maximize the impact on receiving populations.

Influence of mariculture activity on periphyton characteristics and growth performance of sandfish *Holothuria scabra* juveniles reared in nearby ocean-based nursery systems

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The impact of anthropogenic enrichment due to mariculture activity and substrate mesh size on periphyton characteristics and its consequent effects on the growth performance of juvenile (~5 mm) sandfish (*Holothuria scabra*) was evaluated at three sites (i.e. enriched, intermediate, unenriched) along Guiguiwanen Channel in Bolinao Northwestern Philippines using two different substrate mesh size (i.e. 400 µm and 1 mm) in a 30-day field experiment. Growth and survival of sandfish juveniles were measured twice, and periphyton chlorophyll a and ash-free dry weight (AFDW) were monitored every 5-days for 30 days. Sea slugs (Aplysiidae) that recruited inside the mini-hapa nets were identified and counted during monitoring. Results showed that mean length and absolute growth rates (AGR) was not significantly different between mesh size and across sites by day 15; however, by day 30, mean length and AGR of sandfish juveniles were significantly higher at the enriched site. Juveniles reared at the enriched site were significantly larger and grew faster than juveniles reared at sites farther from the fish farm. However, growth rates of juveniles at all sites was relatively low at day 30 compared to day 15. Decreased AGR at day 30 could be attributed to reduced food availability as indicated by lower AFDW of periphyton due to inter- and intraspecific competition. Chlorophyll a concentration was higher during the second half of the experiment; however, total biomass of periphyton, as indicated by AFDW, generally decreased overtime. Decreased food availability coincided with increased numbers of sea slugs that recruited into the mini-hapas towards the end of the experiment. Survival significantly differed across sites but was not influenced by mesh size by day 15. Sandfish survival was significantly higher at the intermediate site by day 15, and was significantly higher for juveniles reared in 400 µm mesh size nets across sites by day 30. Results of the study show that culturing sandfish near a mariculture impacted sites can support increased production of sandfish juveniles. Additionally, the used of finer mesh net enclosures (i.e. 400 µm) resulted in improved survival and production of sandfish juveniles for stock enhancement or restocking purposes.

Theme b. Improving fisheries through habitat rehabilitation, artificial reefs, oyster reefs and spawning reefs

Informing Restoration: Assessing Distributions of Oyster Predators Across Environmental Gradients in the Suwannee Sound, FL

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Eastern oysters (*Crassostrea virginica*) and the reefs they create provide numerous ecosystem services, such as nutrient cycling, habitat construction, and shoreline buffering, and they are a significant economic resource for many coastal communities. Recent collapses of oyster populations and fisheries have drawn much attention and investigation into management strategies and have prompted heightened restoration efforts. There are, however, gaps in our understanding of factors that influence oyster population dynamics which would provide key information for decision-makers of restoration projects. Influences on the foraging behavior of invertebrate oyster-predators have been well-documented in controlled laboratory settings, but the spatial preferences of these predators have not been well understood and documented in situ. Here we implement a field study in the Northeast Gulf of Mexico that assesses oyster-predator densities across environmental gradients, including salinity and oyster density, which could allow more strategic planning of restoration efforts. Comparing different predator densities will demonstrate preferential habitat conditions for predators as well as relative risk of predation mortality by oysters in the estuary. This work will improve understanding of predator movement and their foraging preferences in a dynamic environment and will be useful in oyster reef management and restoration planning to protect natural resources from additional mortality.

Establishing Gamefish Populations in an eco-engineered coastal freshwater lake system; Ecosystem restoration and enhancement of coastal pasture lands in Costa Rica.

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Loss of productive coastal habitats is a common issue worldwide but successful restoration and recovery of these habitats is becoming more possible with improvements in eco-engineering capabilities. This project, located on the pacific coast of Costa Rica, involved the successful conversion of highly-degraded coastal pasture land into productive eco-engineered lake habitat. A highly eroded nearby canal stream also underwent reconstructive engineering to reduce erosion and restore natural meandering flow. The principal ecological objectives of this stream and lake project were (1) to restore natural flow patterns of part of the local rivers, Rio Platanares and Rio Cienaga such that natural fish populations that were once more abundant across the property can thrive once again on the property; (2) to expand nursery habitat on the property for some of the most popular native catadromous gamefish including various species of snook, in particular black snook *Centropomus nigrescens*, through construction of a large upstream eco-engineered lake habitat containing a series of step pools that enable recruitment and migration between the estuary and the

lake, (3) to enhance survival of individual gamefish collected from the wild by stocking them in the lake and allowing them to grow to adulthood without suffering harvest mortality. By releasing a portion of the gamefish back into the wild after they reach maturity, the project is well designed to promote responsible growth practices by integrating environmental stewardship with land development in Costa Rica.

Global trends in artificial reefs: how has design, purpose, location and monitoring method changed over the last 50 years

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The practice of submerging artificial structures has been used for many years in countries around the world to for fill a variety of purposes. This study employed a systematic review of 'western' peer-reviewed literature from the Scopus and Web of Knowledge databases between 1971 and 2019 (n = 1,027) to provide an indication of how trends in artificial reefs change spatially and temporally. Artificial reefs were found to be deployed in marine waters from 56 countries, with the United States, Australia, Italy, Brazil and Japan having the most structures. The number of artificial reefs in a country was highly correlated with their total area of created habitat ($p = 0.001$; $R2 = 0.88$), but this was not related to a country's gross domestic product ($p > 0.05$; $R2 = 0.16$). Published records of deployments go back to 1886, but it was not until the 1970s when the number of deployments increased rapidly. Most (62%) of these structures were deployed in waters < 20 m deep, but some disused petroleum structures extend as far down as 714 m. Almost 80% of reefs were deployed onto sandy habitats, with mud and seagrass (8 & 7%, respectively) being the next most frequent. Over half of the reefs (62%) of the reefs were comprised of a single material (38% were comprised of mixed materials), with those made from concrete (46%) and metal (28%) the most common. Tires comprised only 7% of all reefs recorded. The main purpose of deployment was considered to fit into one of eleven categories, with enhancing fisheries (40%), particularly recreational ones (24%), the most common. Interestingly 18% of artificial reefs were deployed to enhance scientific knowledge. Almost 80% of the reefs were accompanied with some form of monitoring, with underwater visual census being the most readily employed methodology (56%), followed by remote underwater video and line fishing. Spatial and temporal trends in the characteristics of artificial reefs are also explored.

Study on Deployment progress of a Frame-type Artificial Reef Based on 6DoF Model with Dynamic Mesh Method

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Artificial reefs (ARs) were one of the most important part of marine ranching construction, which have been regarded as an effective means for improving ecological environment and maintaining fishery resources in the coastal water. The appropriate deployment method of ARs should be paid more attention because it can affect its layout, which can determine flow field effect (e.g., the upwelling and back eddy). The upwelling and back eddy can promote water exchange between the upper and lower layers, accelerate circulation of nutrients, improve primary productivity and attract fish aggregation. However, the main method of deployment was to lift ARs to sea surface and drop directly, and little

research has concentrated on deployment progress of ARs. These extensive deployment methods might cause large deviation of expected layout. Thus, it was necessary to conduct research on progress of ARs deployment. In our study, we applied 6 degrees of freedom (6DoF) model with dynamic mesh method using the Fluent software, to simulate the deployment progress of a kind of frame-type reef with different operating conditions. The study would explore the pattern of reef trajectory and deviation among various flow velocity, releasing angle and falling height. Besides, both falling velocity and impact force of ARs would be also analyzed. This study could provide some useful references for scientific deployment of ARs.

Exploring the optimum layout of artificial reefs based on species distribution models and computer simulations

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Artificial reefs have been widely used to gather fishes in certain sea areas. The previous studies on the layout of artificial reef mainly depend on flow field simulation methods. This study, based on spatial and temporal distribution of dominant species in artificial reefs area, put forward a method to optimize artificial reefs layout by utilizing species distribution models and computer simulation methods. The experimental area is located in the south-central of Bohai Strait in China, a region of rocky and muddy substrate. By now, twenty-four reinforced concrete reefs of 3m×7m×3m have been put in place. The process of the method is to: (1) Establish machine learning models on the spatial distribution and driving factors of important species, and select the optimal model based on the biodata, water quality and sediment environment of the artificial reef area; (2) Divide the experimental area into regular cells with a resolution of 50m×50m; (3) Change the substrate types' score of cells randomly to detect the effects of layout of reefs on the species distribution with all other driving variables fixed, because the layout of reefs would change the substrate type, and simulate this process for 100,000 times; (4) Find out the optimal numbers and layout of artificial reefs based on the predicted occurrence probability of the dominant economical species and harmful species, in every simulation of reefs layout. Our result shows that the optimal number of artificial reefs in the experimental area is 150. We found two optimal layouts among the 100,000 times of simulation. Because it is unrealistic to move the artificial reefs after the placement, this method made the arrangement of artificial reefs more reasonable ecologically. Consequently, the method proposed by us to optimize the number and layout of artificial reefs is efficient, viable and replicable.

Application of Underwater Soundscape in the Farming Shrimp Pond of *Penaeus Vannamei*

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There are much noise in the sea and some sounds produced by underwater animals, such as Cetacean and so on. Sounds are useful for whales and dolphins to communicate and direct within groups, as well as to capture preys and adapt to the environment. So recently, the concept Marine Soundscape Ecology is proposed by some researchers, with the idea of using underwater soundscape to understand marine ecology. Underwater soundscapes, which are determined by physical measurements of the sound field from all of the sound sources, are dynamic and vary in space, time, and within and between habitats. Whales and dolphins are studied from long term monitoring in the southwestern Atlantic Ocean to provide information about the behavioral ecology. On the other hand, benthic crustaceans live in a local range and are normally used to an indication of environmental impacts. Therefor the knowledge of soundscape is very useful for a broad

understanding of Interaction Impacts for the continental shelf dynamic processes and for the management to conservation purposes. Since the soundscape is related to widespread environmental features and species' evolution, the future of the research depends on gathering baseline information about the natural variation in acoustic behavior of the species. Considering that there are many artificial aquaculture bases along the coast of China, it may be valuable to study this simple case for main questions. Especially *Penaeus vannamei* in China is an economic aquaculture species introduced from abroad. In this study, underwater sound of shrimp ponds was collected to get acoustic behavior of *Penaeus vannamei* in process of large-scale aquaculture. Experiments show that passive monitor can acquire the feeding sounds of *Penaeus vannamei*, which can be distinguished from other noises. In order to explore the sound characteristics and regularity of *Penaeus vannamei* feeding, other experiments were carried out in the freshwater environment, and the signal was collected by hydrophone and collector. Through the spectrum analysis and time-frequency analysis of the signal by Matlab software, sound characteristics of *Penaeus vannamei* are obtained. The results show that the acoustic signals produced by *Penaeus vannamei* have similar patterns before the feeding. After the feeding, sound characteristics are different along with the chewing activity. [Supported by National Natural Science Foundation of China (Grant No. 41374147) and Shanghai Intelligent Agriculture Project (2019-02-08-00-10-F01117)]

Marine Ranching for the Whole Life History of Fish

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The construction of marine ranching in China is gradually changing from the type of proliferating resources to the type of recreational sea fishing. However, the planning and design of the reef type and scale of the artificial reef are basically based on the accumulation of adult fish as the main factor, while the reef type used in the resource-proliferating ranch is mostly stone and small concrete construction. These two construction models ignore the source of adult fish, namely larval and juvenile fish. Taking Shandong Province of China as an example, the main fishing species of marine ranching of recreational sea fishing are mainly reef fishes, such as *Sebastes schlegeli* and *Hexagrammos otakii*. If they are provided with spawning protection reef, juvenile fish, culture reef, adult fish hidden reef and fishing reef in the same marine ranch, they can complete their whole life history in a limited water area. Therefore, in order to solve the problem of insufficient supplementary sources of adult fish in recreational sea fishing, the "whole life history", from larval, juvenile fish to adult fish, was taken as the protection chain to provide spawning, larval and juvenile fish culture, juvenile fish growth and adult fish habitat construction in the same marine ranching. In July 2018, our team put several different types of reefs into the coastal waters of Shuangdao Bay, Weihai City, Shandong Province, China, for the purpose of fish spawning, larval, juvenile fish and adult fish habitat. After a year of water sample and sediment survey, including diving survey, the results show that the habitat and biomass in this area has been improved.

Artificial reefs – too much of a good thing?

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The Magnuson-Stevens Act charges NMFS to work with regional councils to manage federal fisheries with annual quotas to provide the greatest national benefit, including recreational opportunities. State and federal agencies deploy artificial structures for many reasons, often to enhance recreational fisheries. While such structures can improve the angler experience by making fish easier to locate and catch, they can also decrease fishing opportunities by causing quotas to be reached more quickly which reduces access to the resource. Recreational catch rates for the iconic Gulf of Mexico red snapper have expanded 4-fold as the population recovers from years of overfishing. Prior to state management, this trend required fishery managers to reduce the fishing season from 122 days to as

few as 3 days at the same time the quota increased from 5 million pounds to nearly 14 million pounds. The shorter seasons frustrated anglers who value the opportunity to target red snapper, created allocation conflicts, and eroded relationships between fishermen, scientists, and state and federal managers. A 2017 study by Karnauskas et al. found that red snapper catch rates are up to 20 times higher on artificial reefs and up to 26 times higher on platforms relative to natural reefs. Analyses show that even modest (? 5%) shifts in effort from natural reefs to artificial structures could shorten fishing season lengths by as much as 50%. It is possible that artificial structures increase red snapper productivity; however, the debate over whether any resulting increase in red snapper offsets increased fishing pressure remains unresolved and the subject of several ongoing studies. Artificial reefs may also impact fishery allocations by concentrating fishing effort in certain areas. About 40% of the recreational red snapper catch is landed in Alabama, which has just 3% of red snapper domain, but roughly 50% of the artificial structures in the Gulf. The use of artificial structures for fishery enhancement is a complex issue with many tradeoffs. Greater collaboration with federal fishery managers during artificial reef permitting processes, along with additional research, could improve the success of artificial structures in achieving fishery enhancement objectives and reduce unintended consequences.

Effects of artificial reefs on recreational fisheries: what we don't know might hurt us

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Artificial reefs are increasingly deployed in marine waters to appease stakeholders with whom they remain a population management action as they enhance recreational fisheries and restore reef fish populations. Additionally, they provide benefits such as increased economic activity (i.e. income, expenditures) to surrounding communities. While it is certain that reefs alter rates affecting biological and ecological components of fish populations, they may also influence angler behaviors such as site choice, aggregate effort, and catchability. It is also uncertain if these reefs may lead to overfishing due to the attraction and aggregation of existing stocks without increasing overall stock size. The net effects of artificial reefs on the socioecological system and how these reefs may mediate sustainability of the fishery have not been well studied. These gaps in knowledge may lead to unintended consequences of artificial reefs that could ultimately limit their potential and efficacy. To better understand the possible outcomes of artificial reef implementation, we developed a two-dimensional integrated socioecological model representing a red snapper in Northwest Florida and simulated how commonly described effects of artificial reefs and angler behavior would interact to affect the socioecological system. Our results demonstrate that simultaneously achieving both socioeconomic and conservation benefits from implementing artificial reefs is only possible under relatively specific assumptions regarding to how reefs affect fish and fishers. What causes this result is that gains in angler satisfaction and economic impacts from reefs require increased catch and responsive fishing effort, respectively, that ultimately increase fishing-related mortality. To avoid fish population decline, artificial reefs would need to substantially improve recruitment, growth, and/or survival. Absence in these marked improvements could lead to more restrictive fisheries for artificial reefs (e.g. shorter harvest seasons), which would have undesired effects on nearby coastal communities. These results highlight the importance of understanding spatial dynamics of fish population and anglers and the potential of using assessment models as engagement tools to help develop understanding between managers and fishers.

Theme g. Re-stocking and restoration aquaculture

Building resilient coral reefs in the Florida Keys using restoration science

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Millions of dollars have been invested in restoring the Florida reef tract by 're-seeding' reefs with nursery raised corals. However, both wild and nursery raised corals must survive significant environmental changes and extensive threats within the reef environment in order to reproduce and contribute to self-perpetuating population recovery. Mote Marine Laboratory's strategy for coral restoration focuses on propagating multiple coral species with high genetic diversity that are also resilient to some of the most common and severe threats on reefs today and likely into the future: coral disease, increasing oceanic temperatures, and ocean acidification. We conduct precise laboratory exposure experiments to determine the resilience of each coral genotype to these major threats within our reefs. Collaborations with experts in genetics and microbiome characterization assist in the identification of the mechanisms driving resilient traits for each coral species used within Mote's restoration plan. These mechanistic signatures are then used to screen corals for resilient traits both within the restoration platform and within the wild populations. Mote scientists also utilize resilient individuals to conduct assisted sexual reproductive crosses to increase resilience of the offspring while simultaneously increasing genetic diversity of the restoration population. Finally, we utilize the data collected from these exposure experiments to conduct trait-based modeling to assess successful population recovery under different environmental scenarios. The mindful approach that Mote is undertaking will ensure greater success for restoration by outplanting a coral community that is genetically diverse and also more resilient to major threats on the reefs of today and tomorrow.

Developing intensive aquaculture of the long-spined sea urchin *Diadema antillarum* as a tool for coral reef restoration

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The long-spined sea urchin *Diadema antillarum* was once an abundant reef grazing herbivore throughout the tropical western Atlantic. Benthic surveys conducted in the Florida Keys during the 1960-70s revealed average densities of 5-10 individuals per square meter. In 1983-1984, an unidentified disease affecting *D. antillarum* appeared on the east side of the Panama Canal and spread with prevailing currents, causing 93-100% mortality on Caribbean coral reefs. Widespread population reductions from this event resulted in a sudden lack of reef herbivory and increase in macroalgae cover and contributed to an ecological phase shift from hard coral dominated to macroalgae dominated reef systems in many areas. *D. antillarum* population recovery since 1983-1984 has been slow or nonexistent, particularly in the Florida Reef Tract. Attempts to restore resilient coral reefs at significant scale would benefit from replacing some of this lost herbivory via establishment of sexually propagated *D. antillarum*. A critical first step in this direction is the ability to reliably produce *D. antillarum* from gametes. Investigations into *D. antillarum* aquaculture have been occurring for almost 30 years with limited success due to the difficulty and length of the larviculture process. The purpose of this study is to refine methodology for reliable ex situ reproduction and larval

rearing of *D. antillarum* in closed recirculating aquaculture systems (RAS), which would improve the viability of experimental population enhancement. A novel 1800-L RAS incorporating unique 40-L circular larviculture vessels was developed to perform replicated trials aimed at investigating culture bottlenecks and critical phases of larval development. Initial investigations examined the effects of microalgae diet cell densities and diet species combinations on larval development and survival. Larvae reared on microalgae diets containing the cryptophyte *Rhodomonas lens* exhibited greatly improved growth and survival over 21- and 42-day long trials. Rudiment appendage development was also observed in a higher proportion in larvae reared on diets containing *Rhodomonas lens*. Additional data including appropriate larval densities and water quality parameters will be presented. The novel RAS successfully produced juvenile *D. antillarum* and current efforts are focused on scaling up production to reef-relevant levels.

Restocking Southern Rock Lobster with juveniles ongrown from wild-caught puerulus

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Puerulus of southern rock lobsters *Jasus edwardsii* are captured in large numbers on gear deployed for other aquaculture operations in SE Australia, such as oyster baskets and fish pens. This easily collected seed led to research in ~2000 for the collection and ongrowing of puerulus for aquaculture. Those attempts were ultimately unsuccessful because policy could not be developed that enabled transfer of sub-legal lobsters into private ownership. Aquaculture operators have remained frustrated at the waste of these puerulus as current regulations require the current annual catch of perhaps 100,000 to be released, with virtually all of these immediately eaten by fish. An alternate approach is now being explored which involves retaining pubic ownership of the puerulus / juvenile lobsters at all times, which avoids conflict with size limit regulations. Puerulus will be harvested from aquaculture gear and then ongrown for one year (~ 35 g) then released back into the wild with several objectives being explored: (i) to enhance local recreational fishing opportunities; (ii) promote tourism harvesting in locations with especially high growth; (iii) restore lobster ecosystem function for predation of urchins in areas of the coast where barrens are forming; and (iv) restore inshore Aboriginal cultural fishing opportunities. At no point are the juvenile lobsters transferred from public to private ownership which solves the policy barrier. Earlier research has shown that juvenile lobsters can be released successfully with high survival however, numerous technical issues remain around efficient husbandry systems, and these are the subject of current research.

The Special Behaviors and Restoration of Sea Cucumber *Apostichopus japonicus*

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A better understanding of the movement, feeding and spawning behaviors may provide useful information for the development of the aquaculture and restoration of the sea cucumber, *Apostichopus japonicus*. Combining the advanced time-lapse photography technology with professional behavior-analysis software, the behavioral research system for *A. japonicus* has been conducted, and the movement and feeding behavior of *A. japonicus* have been systematically studied. The average movement speed of *A. japonicas* is around 1.6-3.4 cm/min. The effects of different temperature, light and flow velocity on the movement behaviors have been also investigated. The tentacle locomotion, feeding rhythms, ingestion rate (IR), feces production rate (FPR) and digestive enzyme activities were studied. Frame-by-frame video analysis revealed that they had similar feeding strategies using a grasping motion to pick up sediment particles. Feeding activities investigated by charge coupled device cameras with infrared systems indicated that all size groups of sea cucumber were nocturnal

and their feeding peaks occurred at 02:00–04:00. Additionally, the peak activities of digestive enzymes were 2–4 h earlier than the peak of feeding. Meanwhile, the total distance moved and cumulative duration of moving gradually decrease during reproduction and the reproduction also depresses the locomotor endurance. According to the special behaviors and the habitat characteristics of *A. japonicus*, some new multiple-species biological restoration technologies were developed. They have been applied in the coastal areas in Northern China.

Theme h. Integrating aquaculture-based and habitat-based fisheries enhancements: New technologies to maximise outcomes and create opportunities

The development, progress and current state of China's Modern Marine Ranching Program

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In China, marine ranching mainly refers to the deployment of artificial reefs and associated releases of hatchery-reared seed. Over the past 40 years, more than 60 million cubic meters of artificial reefs have been placed along the coast of China, manly comprising concrete and rock. Since the late 1970s, augmentation of marine fisheries resources have also developed alongside deployment of these artificial reef habitats. Since 2008, extensive research on marine ranching has been carried out, including concept development and associated technical approaches including artificial reefs design, hatchery rearing techniques, release strategies, behavioral conditioning, environmental monitoring, resource survey and assessment, selective fishing, and adaptive management. This supported the construction of national marine ranching demonstration zones from 2015, which intends to support fifty-two marine species through marine ranching, and 86 national marine ranching demonstration zones have been approved to date. We provide a synopsis of research, progress, challenges, and outcomes from one of the largest sea ranching programs yet implemented, and identify opportunities for future development.

Construction of marine ranching in China: reviews and prospects

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Marine Ranching is the artificial fishing site where fishery resources are scientifically bred and managed by fully using natural productivity of certain sea areas, based on principles of marine ecology and modern marine engineering techniques. It is characterized with the goal of enhancing stockment, definite boundary and ownership and resources managed in a scientific way. Besides, seedlings are artificially bred or domesticated, released or transplanted into open sea, and mainly fed with natural live feed. As early as 1940s, some Chinese marine scientist, such as Mr. Chu S.P.(Zhu Shuping) and Mr. Tseng Chengkui (Zeng Chengkui), originally put forwards the idea of building artificial ranch in the ocean by planting and cultivating marine creatures. Since 1980s, the Chinese marine ranch construction has experienced three industrial forms including artificial reefs, stock enhancement and systematical ocean ranching. In spite of the great achievement, it is still facing problems including too broad application of its defination, lack of overall planning and feasibility studies, neglecting its ecological role as well as project evaluation and system management. In future, the development of marine ranching in China should recognize the importance of ecosystem, balance industrial arrangement both on the land and in the sea, comprehensively consider the primary, secondary and tertiary industry, realize four modernizations and encourage innovation for leaping development to realize both economic and ecological benefits.

Synthesising aquaculture-based and habitat-based enhancement with an iconic sportfish in a highly urbanised estuary

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Recreational fishing is a popular activity in Australia, with an estimated expenditure of $1.6bn year^{-1}. Fisheries management strategies seek to improve recreational fishing opportunities through both aquaculture-based and habitat-based fisheries enhancement, although historically these are not used together. Yellowtail Kingfish (*Seriola lalandi*, YTK) is an iconic sportfish, however there are concerns regarding the health of the stock. Juveniles are known to frequent reef habitat in estuaries and the coastal zone, but large juvenile recruitment events have not yet been detected. We present the results of a pilot program which released 13,000 juvenile YTK on estuarine artificial reefs and other habitats in two estuaries within the Greater Sydney area. Monitoring involved acoustic telemetry, video surveys, a tag-recapture program and collection of genetic samples from charter boat operators. Early telemetry results show a third of fish remained at the estuarine artificial reef site for up to two months post release. Additional acoustic detections together with recaptured tagged fish suggest many individuals have moved into nearby estuaries and the adjacent coastal zone, including visits to offshore artificial reefs. Outcomes of these monitoring programs will be used to inform future stocking events to improve recreational angling opportunities.

Building New Fishery Ecosystems: The Science of Flexible Floating Fishing Reefs

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Building flexible floating fishing reefs is another tool for fisheries managers – increasing and optimizing fisheries ecosystems. New reefs reduce the pressure on existing degraded ecosystems. Existing ecosystems can become marine sanctuaries while fishing moves to the new reef. The new fishing reef yield depends on its primary productivity. Reef operators can ensure much greater productivity and biodiversity by optimizing the new reef's depth and nutrient return. The depth controls photosynthesis. Inorganic nutrient return controls primary productivity. Timing primary productivity controls dissolved oxygen concentration. In order to operate the new fishing reefs, we will need ecosystem nutrient-flow and populations models for all the life on reef. Reef life includes: microbes, attached growth plants; the plankton around the reef; attached filter feeders; roaming (structure and/or seafloor) creatures; and finfish. Some life will be planted and/or stocked. Most life will volunteer. Reef operators will use the model and market analysis to predict how much of each species will be harvested when. Funding from the U.S. Department of Energy's Advanced Research Projects Agency-Energy's MARINER program allowed several teams to develop open-ocean structures/systems for grow-ing macroalgae. Those structures can be converted to permanent flexible

floating fishing reefs laden with sea creature shelters and harvesting systems. Our MARINER team included a prelim-inary species, nutrient flow, economic, and scaling analysis when using the macroalgae reef as a new form of aquaculture. Fore example, reefs in the Caribbean might harvest: queen conch, lob-ster, Caribbean king crab, octopus, squid, sea urchin, sea cucumber, bivalves, sponges, and free-range finfish – lionfish (over-fish them to local extinction), cod, snapper, jacks, kingfish, macke-rel, whiting, bonefish, barracuda, tarpon, wahoo, grouper, flounder, tripletail, etc. Our scaling and economic analysis suggest that 60,000-km2 of new fishing reefs could feed 10 billion people 300 grams of seafood every day. The seafood would cost US$1 to $2 per kilogram at the dock. At feed-the-world scale, reef operators would be returning/distributing nutrient volumes equiva-lent to either 10 billion people's wastes or a third of global artificial nitrogen production.

New Materials and Strategies for Efficient Large-Scale, Free-On-Bottom Oyster Culturing

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Sandbar Oyster Company (hereafter SANDBAR) is commercializing a patent-pending biodegradable hardscape licensed from UNC Chapel Hill that was co-invented by SANDBAR's co-founders Dr. Niels Lindquist (UNC Institute of Marine Sciences) and North Carolina commercial shellfish harvester David "Clammerhead" Cessna. The degradable hardscape is a composite of plant-fiber cloths, such as jute erosion control cloth, and mineral-based binders, such as Portland cement. The cloth is cut to size, passed through a slurry of the binder and then wet-formed to a variety of shapes tailored for use in oyster aquaculture, restoration of oyster and saltmarsh habitats and the creation of living shorelines. These products have been given the trade names Oyster Catcher™ and Marsh Maker ™. SANDBAR's "oyster shell substitute" form of Oyster Catcher™ is called a Tuft, which is shaped like a 3-dimensional pretzel. Tufts provide high surface area for spat attachment and open space among the Tuft strands that allows attached spat to grow to larger sizes with a minimum of shell fusing among neighboring oysters. In North Carolina, we deploy Tufts in late spring on intertidal leases for seeding with wild spat. Setting with hatchery raised larvae is an alternative for seeding Tufts. Spat-covered Tufts are held on intertidal leases to safely grow juvenile oysters into the late fall when many oyster predators (e.g. blue crabs) and pests (e.g. boring sponges) are becoming less active and reproductively senescent. Seeded Tufts with large juvenile oysters are then broadcast onto subtidal lease tracts (or public bottoms) with no pre-existing oyster-based habitat to minimize their interactions with predators and pests. Over winter, the oysters grow to a size offering refuge from many predators re-entering the estuaries in the spring. By fall, a majority of these oysters have reached market size and have shells largely free of blemishes from shell-eroding organisms. Importantly, the radial structure of Tuft strands limits the contact extent of oyster attachment. Thus, as Tufts degrade, oysters are readily shed as single oysters and small clusters, yielding oysters for multiple market sectors, including half-shell, bushel and sucked oyster products. Sourcing Tuft-derived seed into a row crop-like, free-on-bottom program may enhance per acre yields and profitability, as capital investments in containment systems and labor to manage gear is minimized. Creating rotated ephemeral reefs could support high standing stock biomass, yielding multiple ecosystem benefits, while supporting a sustainable, lucrative harvest.

Small-scale aquaculture, emergent habitats and opportunities for stocking of targeted species

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The blue growth paradigm continues to encourage intensive aquaculture consolidating markets in developing countries and increasing its contribution to the world food supply with different results for

socio-ecological systems. Unfortunately, the pressure on the marine environment also increases the potential for regime shifts. Comparatively, extensive aquaculture of bivalves uses phytoplankton and suspended organic matter as food enabling improvements of both water quality and nutrient recycling while providing alternative income to coastal farmers. Current literature suggests that bivalve's aquaculture can change the seabed not only through biodeposition but also adding biogenic substrate. Whilst these effects may be positive or negative, they seem to depend on hydrodynamic regimes and the scale of cultivation. In southern Chile, a key area for global mussel's production, two-thirds of the industry are small-scale farms (<200 tons yr-1). Accordingly, small bivalves' farms (>12-year-old) were surveyed to investigate if small-scale aquaculture promotes emergent habitats based on biogenic substrate addition. Hydrodynamic conditions seem to mitigate accumulation of biodeposits, sessile species remained similar to reference sites, and increased diversity and abundance of mobile fauna included commercial species were found under the farms. Also, low dominance and greater diversity of primary and secondary habitat-forming species implied a process of habitat cascading. This suggested that bivalves exported from the farms may promote emergent habitats, which implies new opportunities for small-scale aquaculturists. This demonstrates how combining socio-ecological principles in artificial structure design, scale and placement used in small-scale bivalve aquaculture can not only support ecosystem services to people, but support services to ecosystems.

Habitat use of juvenile rockfish *Sebastiscus marmoratus* in mussel farming area: possible essential fish habitat for reef fishes

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Mussel farming habitat distributed in the East China Sea has been expanding in great scales since last century and playing essential roles on stock enhancement for local fishes. Fully understanding on habitat use strategies of local fishes in mussel farming area is meaningful to reveal stock enhancement effects for marine ranching programs. A monthly survey focused on juvenile rockfish *Sebastiscus marmoratus* was carried out from May to July, 2018 in Gouqi island of Zhoushan Archipelago, China, in order to explore its habitat use characteristics in mussel farming area, as well as reference value for marine ranching projects. Trap nets were modified to collect juvenile rockfish. Abundance density and its spatial distribution characteristics, habitat selection strategies, food selection characteristics based on stomach contents analysis, and early life cycles based on otolith rings, were discussed. The Abundance density for juvenile rockfish from May to July was respectively 10±6inds/string, 7±5inds/string and 5±5inds/string, showing a monthly decline trend. Juvenile individuals distributed widely during early month and then moved from offshore side of mussel farming area toward inshore side till its complete disappearance in offshore sites. However, sites with the greatest densities were always located besides shoreline area. Moderate intensity of positive correlation was detected between juvenile densities and average void volume as well as macroalgae biomass from hanging mussel strings base on correlation analysis. High feeding intensity lasted all three months with zero rate of empty stomachs, were revealed by stomach content analysis. Juvenile rockfish mainly fed on amphipoda represented by Caprellidae sp.and Gammaridea sp, together account 99.2% by weight among all its diet composition. Its early stage inhabited in mussel farming rafts lasted about two to three months with average daily growth ring equal to 57±12d. Comparison of homogeneousness and regularity on otolith rings revealed that individuals inhabited in mussel farming area showing much more consistence than those from rocky reef habitats. It is indicated that hanging strings in mussel farming waters became idea habitats for juvenile rockfish by offering much more stable physical environment and abundant food sources, which in turn made great contributions to its stock enhancement and population conservation in local areas. It is concluded that mussel farming habitat around Gouqi island has become seasonal essential fish habitat for reef fishes such as rockfish.

Feeding habitat selection by *Sebastiscus marmoratus* in a Special Marine Protected Area within Shengsi Ma'an Archipelago

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Feeding habitat is one of the essential habitats for fishes. Investigations on fish feeding habitat selection are usually conducted to clarify habitat's ecological function and habitat preference of target fish. It has an important guiding significance for implementation of ecosystem-based resource management and conservation measures. This project focused on the feeding habitat selection of rockfish *Sebastiscus marmoratus* in a Special Marine Protected Area (SMPA), Shengsi Ma'an Archipelago. Physical environment and biota characteristics of typical habitats, main biological characteristics, feeding ecology, potential diet composition and the carbon and nitrogen stable isotope characteristics of *S. marmoratus* were discussed. The feeding habitat selection in typical habitat was analyzed systematically. Our results show: 1) In addition to mussel farming area, *S. marmoratus* was the dominant species in other habitats, especially in seaweed beds. Mussel farming area mainly provides habitat for juvenile *S. marmoratus*. Most suitable water depth for juvenile individuals in spring was 6 m, and 8-12 m for adult ones; 2) Feeding habitat changed with the growth of *S. marmoratus*. A comprehensive analysis on its typical habitat environment characteristics, population structure, feeding habits and prey composition indicated that individuals less that 7 cm in body length mainly choose mussel farming area as their feeding habitats, then move to rocky reefs and seaweed beds for length groups equal or larger that 7 cm. Body length between10.0~13.9 cm become dominant group in sea ranching area, and groups <10 cm or >14 cm in the surrounding reef habitat will eventually move to sea ranching area. The results of this study is capable of providing a theoretical basis for clarifying the conservation mechanism of common habitats in SMPA for biological resources, and providing scientific basis for the protection, sustainable use and management of biological resources in the protected areas.

Assessing fish interactions with oyster aquaculture cages using point-of-view cameras

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Multi-tiered aquaculture cages are becoming increasingly common as a method for raising oysters on a smaller spatial footprint within the Northeast US. Cages constitute complex vertical structure that may create habitat for ecologically and economically important fish species. Documenting ecosystem services provided to fish by aquaculture gear may help inform regulators and fishery managers who make decisions about aquaculture practices and could enhance public understanding of how aquaculture gear interacts with the benthic environment. A series of field experiments were conducted during the summers of 2017-2018 quantifying fish interactions using point-of-view cameras mounted to oyster cages. Two GoPro HERO 3+ Silver® cameras were attached to each cage, one at the top corner looking across the horizontal surface, the second at the cage corner, with a view of two cage sides and the interface between cage and seafloor. Cameras were deployed ~24 hours before the onset of recording to minimize disturbance effects. Video was recorded for 8 minute intervals hourly from 7 am to 7 pm over a complete tidal cycle and during most daylight hours. Seawater temperature, light intensity, and current speed and direction were also recorded during deployments. Video footage

was scored using Observer XT® software, which facilitated viewing of top and side time-synced video recordings simultaneously. Fish abundance was calculated using MaxN, defined as the maximum number of fish of each species observed per 1 minute video segment. A matrix of fish behaviors is under development to describe fish interactions in and around oyster cages to better understand provisioning of services to fish by aquaculture gear.

Development of a Fishermen Operated Pilot-Scale Queen Conch *Lobatus gigas* Hatchery and Nursery Facility for Sustainable Seafood Supply and Restoration of Wild Populations in Puerto Rico

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The queen conch *Lobatus* (*Strombus*) *gigas* is an important fisheries species in the Caribbean that has been overfished. In the U.S. Caribbean, The Queen Conch Resources Fishery Management Plan established a program to help rebuild conch populations in Puerto Rico and U.S. Virgin Is. The majority of the conch "Carrucho" fished in Puerto Rico are consumed locally with little export. With the decline in conch populations in Puerto Rico's state and federal waters, closed seasons, and disruption of conch habitats from hurricanes such as Maria, conch is a prime candidate to be cultured in a pilot-scale hatchery in Puerto Rico. The goal of the 2-yr project (S-K NOAA Award NA10NMF4270029) is to assist with restoration of queen conch fisheries in Puerto Rico by producing conch in a fishermen-operated conch aquaculture facility. The conch hatchery is being built at the Fishermen's Association in Naguabo, Puerto Rico. The first hatchery season will be the summer of 2020. Hatchery-reared juvenile conch will be released into the Luis Peña Channel Natural Reserve no take MPA near Isla de Culebra. The hatchery will be open to fishermen, community, students and visitors to learn about conch aquaculture, biology, conservation and fisheries. A live webcam will broadcast hatchery activities and a conch aquaculture Spanish training manual will be completed. This project will serve as a model, which can be transferred to other fishing communities in Puerto Rico and elsewhere. The project will aid sustainable fisheries practices through aquaculture by working with the fishermen, using the commercial Fishermen's Association's working waterfront, helping provide diversified incomes for the fishery communities, promoting aquaculture practices, and ensuring the conch population is available for future fishing and food security through aquaculture and restoration.

Theme d. Ecological dimensions: Fisheries ecology, fisheries enhancement, and the broader ecosystem

Stock enhancement in Sea of Galilee

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Stock enhancement is Sea of Galilee is carried out over the last 50 years' in Commercial-scale. Stock enhancement in the Sea of Galilee serves two purposes: 1. To Increase fish harvest from the lake for the local fishermen; 2. A tool to maintain ecological balance in the Sea of Galilee, which has served over the years as the main source of drinking water in Israel. The lake is exposed to a variety of variables, some of which are natural, such as changes in water level (evaporation), temperature changes, invasion of species, thermal laying & bird migration, and some of them are man-made, such as increasing population along the coastline, washings of nitrates from agricultural areas around the lake & pumping water for the national water carrier of Israel. All of which affect the ecological balance of the lake. The lake is characterized by the blooms of various types of algae. The most significant damage to the quality of the lake water is the bloom of Peridinium algae that release toxins into the water. By management of the fish populations we can help to prevent algae blooms in general, and minimizing the growth of Peridinium in particular. Sea of Galilee is a closed lake, which receives surface water containing nitrates, and there is no exit of water from the lake. Carbon and hydrogen contain a gas state in their circuit, phosphorus does not, and it is a limiting factor to primary production. Each incoming molecule of phosphorus is converted into algae in the process of photosynthesis. The most effective way to remove phosphorus from the lake is by removing fish that convert the phosphorus into biomass. Therefore, the policy is to encourage commercial fishing in the lake. For this purpose, two main species of fish have been stock in Sea of Galilee, which constitute an ecological contribution and have a high economic value. 1. *Sarotherodon galilaeus* - Feeds on Peridinium algae; 2. *Mugil cephalus* - Humnivore, feeds on detritus from the bottom. In order to extend the successes of the stock enhancement project we are conducting a series of studies that include development of unique methods for marking the fish on a genetic basis, and marking the fish with CWT in order to improve and maximize the success rate. In the lecture I will talk about the activities we perform in Israel, and will present the successes, failures and impediments over the years, and present series of studies we are conducting to promote the subject.

Fishery stock enhancement of Chesapeake blue crabs

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From 1991-2001 stock biomass of Chesapeake blue crabs declined 84% and remained at record low levels in the early 2000s with indications of overfishing and recruitment limitation. During 2002-2010, we conducted feasibility tests of enhancing the stock using a “responsible approach”. We released 60+ batches of 2,000-20,000 hatchery reared juveniles (>350,000 total) into nursery habitats. All juveniles were micro-wire tagged to distinguish hatchery from wild crabs in field sampling that tracked survival and growth of cohorts from release to maturation. With tethering experiments for mortality and surveys of food resources, these releases showed that recruitment was indeed limited in nursery habitats: average enhancement of 300% and production of 550 crabs per hectare (range 100-1,600 crabs). Moreover, our release strategies optimized the success of enhancement as a function of 1)

size at release; 2) timing of release. Releasing hatchery crabs at a small size is advantageous to avoid cannibalism in rearing tanks and the increased costs of grow-out. However, release size represents a tradeoff since predation in the field is size dependent, with smaller individuals suffering higher rates of mortality. Mortality negatively correlated with size < 50 mm and optimal release size was 20 mm. Similarly, the optimal release strategy varied with seasonal fluctuations in abiotic factors and predator abundance. Cohorts of juveniles released early in the season grew to maturity within the season of release; whereas cohorts released late in the season over-wintered and grew to maturity in the second year. Field data were then integrated to parameterize a model to predict the relative production of mature females for hatchery-reared crabs under varying release scenarios. Production increased with increasing size at release independent of season; however, size at release was most important for summer releases when predation rates were highest. Production of mature females was maximized in early spring releases, which allowed hatchery-reared crabs to attain a relative size refuge prior to peak predation in summer. Hatchery-reared juveniles from spring releases matured during their first growing season and contributed to the spawning stock in their first year. We tagged mature female crabs entering the fishery with visible external plastic tags so that fishers could report data on capture during migration to the spawn area and inform spatial management. The results of this study provide critical information for identifying optimal stock enhancement strategies for the blue crab in Chesapeake Bay, and provide necessary inputs for both stock assessment and ecological models.

Ecological feasibility of red king crab stock enhancement in Kodiak, Alaska

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Red king crab, *Paralithodes camtschaticus*, was commercially important around Kodiak, Alaska, USA in the 1960s and 1970s; however, the stock crashed in the late 1970s and has failed to recover despite the commercial fishery being closed since 1973. The use of hatchery-reared juveniles has been considered to help bolster the wild population. We examined the effects of release density on in situ survival of hatchery-reared red king. Juveniles were released at three densities, 25, 50, and 75 m-2 in Trident Basin, Kodiak. We monitored densities inside and outside of release plots for 5 months using quadrat counts to determine loss and emigration rates. Relative predation risk was determined using tethering experiments repeated monthly for the first 3 months after release, and predator densities were quantified using quadrat counts and predator transect counts. Initial mortality over the first 24 h was approximately 68%. Loss rates after the initial mortality did not differ among density treatments and were a combination of mortality and emigration. Relative predation risk of tethered crabs decreased with time from release, but did not vary among density treatments. Predator density did not vary over time or with density treatment. Estimates suggest mortality rates of hatchery-reared juveniles was similar to that of wild individuals in a commercially harvested population in southeast Alaska, indicating that stock-enhancement may be ecologically viable, at least during the early benthic phase of the crab's life-history. Initial results from a second, similar release experiment in which the timing of release was varied will also be presented. Future work should focus on ways to reduce initial release mortality.

Ocean Acidification Impacts Survival of Juveniles and Reduces Shell Resistance of Adult Abalone *H. tuberculata*

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Ocean acidification (OA) is a major global stressor that leads to substantial changes in seawater carbonate chemistry, with potential significant consequences for calcifying organisms. This is a major matter of concern for marine species, especially for metazoans that do not control their extracellular pH, like mollusks. However, the different developmental stages might not be sensitive to OA in the same proportion. The objective of this study was to investigate the effect of OA on different stages of the European abalone using a transgenerational and multi-parameter approach. According to IPCC (2014), surface ocean pH might decrease of 0.3 units by 2100. Therefore, adult 3.5-year-old *Haliotis tuberculata* were exposed to two pH conditions (8.0 and 7.7) during 5 months by increasing CO2 partial pressure into five experimental tanks per condition (n = 26 per tank). The effects of decreased pH were assessed on several parameters such as behaviour (circadian rhythm, feeding behaviour, hiding, predator and righting test), physiology (phagocytosis efficiency, respiration, excretion, calcification, haemolymph pH), shell resistance, shell microstructure, growth, and gonad investment. Adult abalone were induced for spawning. Gametes, fertilized eggs, larvae and juveniles were exposed to the same pH condition as their parents (8.0 and 7.7). Survival, development, growth index and shell calcification of larvae and juveniles were assessed from eggs to 5 months of age. No effects of decreased pH were observed on adult abalone metabolism, immunity and behavior, suggesting that adult abalone maintain their vital functions when facing OA stress. However, a significant reduction in shell growth, calcification, microstructure and resistance were observed. For larvae, a decrease of larval shell length and calcification as well as development abnormalities were observed on veliger stages. In addition, juvenile mortality was increased between post-larval fixation and 2.5 months of age. Consequently, OA might represent different concerns to address in the future for abalone fisheries and aquaculture (1) Larvae and juveniles are the most sensitive stage which might impact the success of recruitment (2) Adults might be also impacted with a reduction in abalone protection from predators. Juvenile abalone are produced in hatchery for ranching and sea-enhancement abalone program, with a possibility to control sea-water pH during the first months of juvenile growth. However, abalone hatchery will need to integrate this risk and cost in their management program.

Achieving Restoration Success Under Conflicting Socioecological Objectives

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Oyster ecosystems are subject to a litany of natural and unnatural perturbations, both of which are increasing in frequency and intensity, leading to more restorative management actions. Oyster restorations often have multiple objectives that may conflict in the short run, particularly in areas where oysters are harvested commercially. For example, setting a goal of increasing oyster abundance maybe difficult to achieve while also attempting to support socioeconomic recovery of coastal communities. Here we assess how restoration success may depend on spatial dynamics of oysters and their fishers, as well as the conditions under which additional fishery regulation may be necessary to achieve optimal outcomes. We developed a spatially explicit, socioecological model of a coastal oyster fishery that includes oyster larval and recruitment dynamics as well as dynamic fishing effort and spatial allocation. We then subjected the simulated population to different types of perturbations and potential restoration responses, with and without additional harvest regulations. What our results

reveal is that under some perturbations and patterns of spatial connectivity, restoration actions alone could actually exacerbate population decline if fishing regulations are unchanged. However, limiting fishing effort during restoration certainly affected economic activity likely critical for human communities. We suggest that the most effective oyster restoration may need to be coupled with fishery regulations but also human community aid if the socioecological system function is to be restored.

Reestablishment of a Queen Conch, *Lobatus gigas*, Breeding Population in a Marine Protected Area in The Bahamas

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The queen conch, *Lobatus gigas*, is key to the Bahamian way of life as a cultural icon, food source, and economic resource. Recent studies suggest that commercial stocks will be depleted in The Bahamas in 10-15 yrs. To assist in restoration of the species, a queen conch adult population was reestablished in a historic breeding ground in Moriah Harbour Cay National Park, Exuma, Bahamas. In May 2019, conch from two distinct populations with lip thicknesses, 2-28 mm, and shell lengths, 17-25 cm, were bought directly from the fishermen's boats in Georgetown, Great Exuma, Bahamas. Of these conch, 67% are adults with a lip thickness of > 15 mm and approximately 58% were females and 42% were males. All 255 conch were tagged and stocked in a 0.14 ha circular enclosure at an equivalent of 1,821/ha. The enclosure is located on a back reef in a water depth of 2.5-4.5 m; it is exposed to ocean and bank water and consists of rubble, sand, and sparse to dense seagrass. From May to August 2019 (10 wks) the site was surveyed every 24-48 hrs to study conch movement, burial, predation, breeding, and egg mass laying. In the first month the conch acclimated to the site while recovering from their long-distance transport and shell damage. During this time 90% of the conch were aggregated in the dense seagrass area. In the second month the conch were found throughout the enclosure. Conch actively fed during the day and evening hours. Mating was observed; however, no egg masses were laid during the study period. The flora and the sediment of the site were surveyed monthly inside and outside of the perimeter of the enclosure to characterize any habitat changes from the presence of conch and their grazing. The fauna including predators were also monitored at the site. It is anticipated that this partnership project will result in a path to reestablish more breeding populations in Marine Protected Areas in The Bahamas.

Theme j. Policy and governance: Are policies supporting responsible enhancement keeping up with opportunities?

Restocking in Chile: Identifying Research Gaps and Implementation Challenges for an Ecosystem Approach

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In Chile artisanal fisheries stocks are vulnerable and declining. This trend is emphasized by loss of habitat and resilience of marine ecosystems. However, human-modulated strategies for rebuilding productivity of artisanal benthic fisheries are reported since 80s. Several native species have been proposed as suitable candidates for restocking but mostly driven by their market value. Consequently, restocking and similar strategies are continuously requested by fisher's organizations to improve the productivity of depleted fishing grounds. Considering the relevance and extent of artisanal fisheries and the feasibility of having hatchery-reared species, is necessary to evaluate the impact of restocking actions on the productivity of commercial species. Accordingly, this review aims to categorise the past and current state of restocking, stock enhancement and translocation initiatives in Chile using all literature sources available, including monitoring reports from Management and Exploitation Areas for Benthic Resources. The analysis quantified type of initiative (commercial or experimental), strategy (restocking, stock enhancement, translocation), species, parental stock, releasing method and density, releasing period, monitoring methods and post-assessment processes. The resulting context was used to identify research gaps, further challenges and recommendations for the implementation of an ecosystem approach and those responsible for its commissioning. Finally, the existing regulatory framework, government tools for restocking actions were also evaluated. Approximately 150 restocking actions were reviewed, involving 18 species among seaweeds, invertebrates and fish. 60 % of the initiatives correspond to translocation and approximately 40% used hatchery-reared individuals. The gastropod *Concholepas concholepas* and the sea urchin *Loxechinus albus* were the species most frequently targeted. Genetic objectives and breeding stock characterization were absent. Survival and quantitative measures of success were poorly described as the ecological risks of the stocking actions. This suggested that the goals of stocking programs were motivated by immediate socio-ecological pressures in depleted fishing grounds following a subsidy based-model leading to failure of government initiatives to provide coherent management to protect depleted stocks. The eminent cases are detailed to exemplify observed gaps and challenges. Based on these results and trends, a conceptual model for implementing a country-level restocking program under an ecosystem approach is proposed and discussed.

The parallel dimensions of fisheries enhancement: evaluating societal support for stocking small-scale recreational estuarine fisheries

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Aquaculture-based enhancement is increasingly being used to as one of a suite of fisheries management tools to help sustain stocks and fishing experiences in the face of increasing pressures. While the biological component of enhancements are relatively well studied, less focus has been placed on the 'parallel' social and economic dimensions, particularly in Australia. Thus, in this study of two multisector finfish (Black Bream; *Acanthopagrus butcheri*) and crustacean (Blue Swimmer Crab; *Portunus armatus*) fisheries in south-western Australia we; (i) elicited and measured the strength of recreational fishers' beliefs and associated attitudes regarding enhancement; (ii) compared the level of support for enhancement against other fisheries management tools and (iii) estimated the willingness to pay for such enhancement. The results demonstrate that recreational fishers believe that stock enhancement could have strong positive outcomes, but also recognise that this management strategy could lead to some negative outcomes, such as impacts on co-occurring species and increased fishing pressure. However, these negative outcomes are perceived as less likely to happen than positive ones. Enhancement was supported by the vast major of both crab and bream fishers (87% and 93% respectively). In comparison to alternative management options, only minimum size limits were more socially-acceptable than enhancement. Almost two thirds of respondents (~ 65%) were willing to pay a fee to support releases of hatchery-reared individuals, > 20% lower than the proportion of fishers who supported enhancement. The marginal willingness to pay values for enhancement ranged from AUD $0.30 to $105, with an average of AUD $15 for crabs and $20 for bream, the latter of which is about half the cost of a recreational fishing licence (AUD $40). The lower value for crab enhancement occurs despite those fishers earning larger salaries than bream fishers and likely reflect the social dimensions of those fisheries, i.e. with crab fishers being highly food-motivated and pay relatively little in equipment costs (AUD $29 per trip), whereas bream fishing requires more costly equipment (AUD $203 per trip) and is generally catch-and-release. Our study highlights the importance of integrating these parallel dimensions into fisheries research and management to help ensure effective management of the fishery.

Adaptive Management is a Fundamental but Often Lacking Enhancement Policy

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As marine aquaculture technology experienced a rapid growth phase over the past 3 decades, so, too, have initiatives multiplied that use aquaculture organisms for restoration, restocking, stock enhancement and sea ranching. Many of these initiatives are stakeholder driven and frequently the result of governmental policy decisions and are government funded. Whereas most aquaculture-based enhancements invest strongly in hatchery management, hatchery infrastructure and hatchery production, many share a common weakness – they do not have the resources needed to conduct an adequate scientific evaluation that could help guide management decisions needed to achieve success. This frequently results in stocking programs that lack a monitoring program funded and structured well enough to provide feedback on the effects and effectiveness of enhancement management decisions. Lack of a dedicated monitoring effort results in confusion about fundamental management issues that mediate success and can cause high short-term post-release mortality, poor outcome, and lack of returns needed for assessing effectiveness of the program and making decisions about continuing it. A simple process is discussed for encouraging policy makers and funding providers to include quantitative feedback mechanisms needed for critical management decisions – better known as 'adaptive management'. Educating stakeholders and policy makers about the need for structured, quantitative feedback as a fundamental component of fisheries-enhancement and restoration attempts needs to be addressed early in consideration of new programs and enhancement-reforms.

Symposium synthesis: Emerging themes and connections in fisheries enhancement and restoration aquaculture

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The combined, 6th International Symposium on Stock Enhancement and Sea Ranching and 10th FSU/Mote Symposium in Fisheries Ecology aimed to bridge multiple disciplines and communities of practice. Known variously as fisheries enhancement, restoration aquaculture, artificial reefs, habitat restoration, etc., the disciplines and communities of practice are largely separate but share many common questions, theoretical foundations, and practical issues. In this closing presentation, we aim to highlight recent advances in the different fields, to draw out commonalities and differences, and to outline areas and approaches for fruitful collaboration.

Poster presentations

Theme a. Developments in the science base of aquaculture-based enhancement: biology, ecology, and genetics

First step in the preparation of stock-enhancement for the European abalone (*Haliotis tuberculata*) in Brittany, France

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The genus *Haliotis* is distributed worldwide, with more than 75 species. In recent decades, most stocks of commercial species have been overexploited. As a result, some populations have largely declined and became extinct in some areas. To reintroduce abalone species in those areas or to support declining stocks, resettlement operations have been conducted around the world. They consist of releasing hatchery-reared juveniles (15 - 30 mm), and have led to variable survival rates that are generally low after several months (from 1% to 40%). This mortality is mainly attributed to predation and physiological stresses. In addition, the rearing of juveniles in captivity and resulting domestication can lead to behavioural and physiological changes compared to wild individuals. Thus, behavioural changes are likely to increase the vulnerability of hatchery-reared abalones to predators or various abiotic stress. To better understand the impacts of breeding methods and domestication on behaviour, and therefore on the success of resettlement operations, we conducted experiments on the behaviour of juvenile abalones (*Haliotis tuberculata*) in controlled conditions. The objective was to determine whether restocking operations with juveniles whose parents come from breeding (selected for their growth) is applicable. For these experiments, two abalone lines were selected. The first line (line 1) came from parents that have been selected for 2 generations, on a growth criterion. The second line (line 2) came from wild individuals. Juveniles of both lines experienced the same rearing conditions, in the farm “France Haliotis”, Britany, France. We exposed N=25 individuals from each lineage to two predation tests. In the first test, the arm of a starfish (*Marthasterias glacialis*) was placed in contact with the abalone foot. In the second test, we mimicked a crab attack by applying strong pressure between the foot and the top shell. For both tests, we analysed the escape behaviour. For all the experiments, individuals were used just once. At the same time, we also studied the circadian rhythm in aquariums of N=72 individuals from line 1 and N=72 individuals from line 2 over a 14-day period. Half of the individuals were placed in the presence of a predator (wild *Necrora puber*). We analysed abalone movement and mortality rates for both lines. These experiments are a first step in the preparation of experimental restocking operations in Brittany (France). They will be followed by genetic and phenotypic analyses with hatchery-reared and wild abalone.

Theme b. Improving fisheries through habitat rehabilitation, artificial reefs, oyster reefs and spawning reefs

A best practice strategy to designing and siting offshore artificial reefs to enhance recreational fisheries

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Although they can be built for various purposes, artificial reefs are most well known for their deployments to enhance fisheries, particularly recreational fisheries. In many countries artificial reefs have now become important elements of integrated fishery or coastal management plans. The expectation is that assemblages of fish that recruit or migrate to artificial reefs become similar to assemblages on natural reefs, and given many of these species are popular target species for recreational fishers, it is expected that fishers will benefit if the species are able to be caught consistently. However, many deployments have failed to achieve this goal, largely as a result of poor design and planning. Further, even if catches meet expectations, there are potentially other risks associated with artificial reef deployments. Foremost among these are that there may be negative aspects of increased fishing efficiency on the sustainability of fishing some species, that artificial reefs could potentially be ecological traps or that they could become marine pollution. A new (strategic) approach to deploying artificial reefs for enhancement of recreational fishing is long overdue. To develop their full potential, an approach is needed for designing and refining deployments that considers how best to manage the potential for benefits and risk. We propose a best practice strategy for artificial reef deployment for recreational fishing enhancement that uses the weight of evidence in the literature to determine best practice design criteria and risk minimization approaches. Each component of the strategy is considered essential to optimize enhancement and minimize the potential for risk. The components include: (1) prioritizing and selecting target species for enhancement that considers not only species' popularity but also their ecological, biological, life-history requirements and patterns and vulnerability to overfishing; (2) designing artificial reef modules so that they are tailored to target species; (3) optimizing spatial arrangements of modules; (4) a process for siting that optimizes enhancement and avoids deleterious effects; (5) defining quantitative measures of success; and (6) adaptive management. A case study for a deployment in Northern Territory in Australia is given to show how such a strategic approach can work in practice.

Effects of Artificial Reefs on the Meiofaunal Community and Benthic Environment - A Case Study in Bohai Sea, China

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Artificial reefs are widely deployed for fishery enhancement and marine conservation. A comprehensive assessment on the effects of artificial reefs could minimize the negative consequence of blindly developing artificial reefs. We examined the meiofaunal community and benthic environment adjacent to and less than 5 m from artificial reefs in Xiangyun Bay, Bohai Sea, China. We found the

highest total meiofaunal abundance beside the artificial reef. Shannon-Wiener and Pielou indexes had no significant difference among different distances from the artificial reefs. The presence of artificial reefs impeded the surrounding flow and provided additional substrate for bivalves and kelps, which could cause finer sediment and organic enrichment around it. Sediment grain size and total organic matter were the most important parameters influencing the meiofauna. We suggest that the shape, material, configuration and location of artificial reefs should be related with a specific goal to avoid mindless proliferation.

Scientifically robust citizen science monitoring of artificial reefs

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To comply with national and international sea dumping and other regulations, artificial reef deployments are often accompanied with a legislative monitoring requirement. Given the marked increase in the number of such reefs being constructed around the world and their relatively high costs, there is a need to develop cost-effective but scientifically-robust approaches to monitoring. As many artificial reefs in Australia are deployed to enhance recreational fishing, we partnered with avid fishers who utilised three artificial reefs in south-western Australia to develop a citizen science monitoring program. Volunteers were trained and provided with baited remote underwater video (BRUV) and collected footage from the artificial reef and/or a nearby control site monthly. Unlike some citizen science programs, which have been criticized for generating unreliable data, in this study data from the video footage was extracted by professional scientists and thus accurate. Resultant analyses have generated the following results. 1. BRUVs need to be deployed for at least 45 minutes to 'capture' 95% of the faunal composition. 2. The composition of the fish community on the artificial reef, i.e. number of species, number of individuals (total MaxN) and faunal composition, each varied significantly spatially (among reefs) and over time (monthly over one year). 3. The artificial reefs, each made from thirty 3 m3 'Fishbox' modules, yielded a significantly larger number of species and number of individuals both as a total and of key recreationally-targeted species (e.g. sparids, carangids and platycephalids) than the nearby control site. These results showcase the value of building partnerships with recreational fishers to facilitate the monitoring of artificial reefs and provide some evidence that these reefs have enhanced recreational fishing.

Spatial and temporal trends in faunal composition of natural and artificial reefs in the Yellow Sea

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Marine ranching, a combination of habitat rehabilitation/enhancement and aquaculture-based enhancement, is being widely implemented along the coastal sea of China as the technique means to restore aquatic environment and increase fishery production. However, the ability of artificial structures

to mimic natural habitats for fauna has not been evaluated. This study examined the benthic fish and macroinvertebrates assemblages (sampled using trap nets) of artificial reef complexes deployed in shallow, nearshore (9–11m) and deeper, offshore waters (20–30m) in the Lidao artificial reef zone (Yellow Sea, China) to determine whether they differed from assemblages on adjacent habitats: i.e. natural reefs in nearshore and bare substratum in offshore waters. It also investigated the extent of any temporal variation in these assemblages. A greater total number of taxa were identified in offshore than nearshore waters, but nearshore waters supported higher total mean numbers and biomass. No significant differences were detected in the characteristics of the benthic fish and macroinvertebrate fauna between artificial reefs and their corresponding natural habitats in both depths. Faunal composition in both depths showed strong patterns of temporal variation, mainly due to changes in the abundance of some transient fish species such as *Conger myriaster* and *Pseudopleuronectes herzenstein*, which matched seasonal patterns in water temperature and clarity. The similarity of community structure between nearshore artificial reefs and natural habitats implies that the artificial reefs are mimicking natural habitats, which facilitates functional connectivity. Thus, in the Lidao artificial reef zone, artificial reefs and natural habitats can be considered as integrated habitat management units. In the offshore waters, however, the lack of a difference in composition between habitats possibly reflects the observed sinking of the artificial reefs. This highlights the importance of detailed site assessments before the deployment of artificial reefs, particularly in silty sediments.

Theme c. Hatchery technologies to improve enhancement outcomes and manage genetic risks

Prey Capture Kinematics of Wild and Hatchery Juvenile Common Snook *Centropomus undecimalis*

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Common snook *Centropomus undecimalis* is an important estuarine-dependent predatory fish species in the US. In Florida, the decline of the wild stocks, due mainly to fishing pressure and loss of habitat, along with its popularity as a sport fish, has led to increasingly restrictive management actions in the last 50 years. This has also promoted its culture for stock enhancement as one of many management measures to improve wild populations. Stocking efforts indicate that survival of snook fingerlings can be poor and improvements could be achieved through pre-release conditioning. Hatchery-reared fishes, accustomed to pelleted diets and naïve to feeding on live prey in the wild are generally slower to attack, have lower successful capture rates and are less efficient at consuming prey than wild conspecifics. In this study we compared prey capture kinematics between naïve hatchery juvenile snook and wild conspecifics. Capture behavior quantified with high-speed cameras, identified specific differences in prey capture of hatchery and wild snook. Video analysis revealed that naïve juvenile hatchery snook, exposed to live prey were characterized by fewer fish attempting to feed, exhibited increased ram and significantly greater suction than wild fish had more failed strikes and a slower improvement of the time-to-strike, resulting in a decreased level of feeding success. However, repeated live prey conditioning events resulted in improvements of hatchery snook feeding efficiency, similar to wild fish. Therefore, pro-active hatchery conditioning via exposure to live prey could improve feeding performance in the wild and increase post-release survival.

Theme d. Ecological dimensions: Fisheries ecology, fisheries enhancement, and the broader ecosystem

To stock or not to stock, that is the question: Identifying productivity bottlenecks to inform management responses

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Penaeid prawns are highly fecund, fast growing species that are exploited through several high value commercial fisheries. Most species have a Type-II lifecycle with an estuarine juvenile phase and oceanic adult phase. Eastern School Prawn (*Metapenaeus macleayi*) support an important penaeid fishery in eastern Australia, which in turn supports a large part of the recreational bait sector. However, productivity of this species has decreased in recent years. Stocking has previously been used with considerable success to improve productivity of penaeid prawns, but only where recruitment limitation was evident. We present the outcomes of a comprehensive case study to identify potential productivity bottlenecks for this species, to support management actions aimed at enhancing productivity. Specifically, recruitment limitation and juvenile habitat quality were evaluated. Research identified that catchment-based activities lead to the loss of important structural habitats, and exposure of acid sulfate soils in the catchment was impacting water quality within the juvenile nursery. Sedimentation and lack of flushing in tributary systems led to periodic hypoxic or anoxic conditions penetrating the nursery area, lasting up to 2 weeks. Conditions measured in the field were replicated in the laboratory to establish critical thresholds for the species. Conversely, there was exceptional natural recruitment to the juvenile nursery, relative to observations in other systems. However, deteriorating water quality from catchment runoff, and hypoxic events, led to significantly lower somatic condition in juveniles School Prawn in the nursery. Taken together, the results of this case study indicate that the system is supplying sufficient wild recruits, however conditions in the estuarine nursery are contributing to mortality, as well as other sub-lethal impacts such as a loss of condition. Consequently, although stocking of prawn postlarvae was suggested as a potential management response, the comprehensive evaluation presented here indicates that this is not an appropriate strategy for the studied system. It is likely that other remedial action in the catchment, such as remediating acid sulfate soils and increasing tidal flushing of the tributaries, should improve juvenile survival and address productivity bottlenecks. Future research should evaluate the presence of similar stressors in other estuaries containing important juvenile nurseries for the species, to establish whether these bottlenecks are pervasive.

Evaluating the ecological effects of artificial reefs construction in the coastal water of Shandong Peninsular, China

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Artificial reefs present a typical strategy for stock enhancement, often aiming to promote marine environment and rebuild crucial habitat for spawning, feeding and refuge for fish and other organisms. To date, artificial reefs have been developed in massive programs worldwide; however, the success of this strategy have been reported case-specific, and in most cases, there is a lack of systematic assessments on the environmental and ecological benefits or impacts. The situation applies to the coastal areas of Shandong Peninsular, China, where a large number of artificial reefs have been and will be constructed in the recent years, whereas the necessity and expectation of them is open to debate without solid scientific supports. We start a research program since 2019 to evaluate the effects of artificial reef construction on the marine environment and ecosystem per se and in adjacent waters. The ecological effects are considered in multiple aspects, including hydrology, sediment, nutritional elements, plankton, benthos, and nektons especially fish. We select a sea ranching field in Qingdao where artificial reefs has been implemented for year as a representative study area, and design three-year continuous surveys to collect environmental and biological information in waters inside and outside the artificial reefs. The survey data will be compared among sampling sites in a gradient of the distance from the core of artificial reefs, and a set of statistical methods, including multivariate analyses and joint species distribution models will be used to infer the ecological effects statistically. In addition, mechanistic ecosystem models developed on the basis of the survey data can be used to reflect the ecosystem structure of the studied and adjacent area, from which simulations can be conducted to project the future changes of the artificial reef ecosystems with respect to environmental changes and human activities including recreational fisheries. In summary, the research program aim to demonstrate a systematical framework for assessing the effectiveness of artificial reef from an ecological perspective, which may be valuable to guide future development of artificial reef for stock enhancements.

To stock or not to stock: the estuarine enhancement paradox

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Selecting the most appropriate target species for aquaculture-based enhancement and the release environment is critical for the success of any program. In Australia it has been argued that such programs should be undertaken in estuaries due to their high productivity and involve species that are confined to estuaries. Yet, estuaries are dynamic in terms of their physico-chemical conditions and those systems that are microtidal (tidal range < 2 m) are particularly susceptible to deleterious anthropogenic effects and climate change. We illustrate the trade-offs with restocking species that are confined to estuaries using the Western School Prawn (*Metapenaeus dalli*), which completes its life-cycle within the estuary and does not have a source of recruitment from adjacent marine waters. Between 2012/13 and 2015/16, 4.5 million hatchery-reared postlarval prawns were released into the microtidal Swan-Cannning Estuary and the density of M. dalli recorded monthly during the breeding season (October-March) in five years between 2013/14 and 2017/18. Densities and egg production increased successively in nearshore and offshore waters during the first three years of stocking, with increases of 58 and 109% for density (relative to 2013/14) and 1,912 and 124% for egg production, respectively. However, in the following year, localised hypoxic events and atypically low temperatures caused densities in both water depths to decrease by > 90% and egg production by 85% compared to pre-restocking levels. Moreover, atypical summer rainfall in 2017 led to extensive and persistent hypoxia, and, in the following breeding season, densities reached only 4% those of 2013/14, with a similar albeit slightly less pronounced reduction in egg production. While the abundance of *M. dalli* changed markedly, that of another large penaeid the Western King Prawn (*Penaeus latisulacatus*), which spawns in marine waters and whose juveniles use the estuary as a nursery area, remained far more consistent. This highlights the trade-off of using aquaculture-based enhancement for estuarine species and thus the estuarine enhancement paradox. By enhancing stocks of resident species individuals remain in the estuary and contribute to catches and egg production, however, they are also

susceptible to deleterious atypical climatic events, which are predicted to occur more frequently with climate change in this region.

Theme h. Integrating aquaculture-based and habitat-based fisheries enhancements: New technologies to maximise outcomes and create opportunities

Variation in growth of sea-ranched abalone on artificial structures

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Ocean Grown Abalone (OGA) established a sea ranching operation for Greenlip Abalone, *Haliotis laevigatus*, in Flinders Bay (south-western Australia), where hatchery-reared juveniles are grown to 40 mm (shell length) and released onto artificial habitats (Abitats). These structures are 0.9 m high concrete pyramids, 2m wide at the base, with a surface area of 10 m2 and weight of 900 kg. The 10,000 Abitats installed on the seabed between August 2014 and November 2018 produced 55 tonnes of abalone in 2018/19. At full production the ranch will produce 200 tonnes, which is much greater than the yield from all Greenlip capture fisheries in Western Australia. Abalone yield varies spatially across the ranch and OGA have developed three alternative designs of artificial structures, i.e. horizontal, vertical and flatpack, to investigate the influence of structure design on the performance (i.e. growth and survival) of released abalone. Thus, the aims of this research are to assess (1) the level of variability in growth across the ranch; (2) the influence of artificial structure design on growth and survival; and (3) how variability in growth effects harvest yield and value. Initial surveys of counts and shell length measurements by commercial divers suggest that both the horizontal and vertical designs retained a higher mean percentage of seeded abalone than the Abitats and flatpack designs, suggesting these structures may provide greater protection from predators and/or increased food supply than Abitats or flatpacks. Within the ranch, abalone were found in greatest numbers and at larger sizes in different locations, suggesting that these areas may provide the best conditions to enable growth, namely plentiful oxygen supply and good supply of drift algae (food). These initial findings will be evaluated in more detail by tagging individuals and evaluating the economic consequences of these differences in growth and survival for the production of the ranch.

Community and biodeposit monitoring of raft cultural system reveals the potential of artificial cultural structure as marine ranching habitat and the need for comprehensive management

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With a growing human population that requires high-quality protein, the demand for fish products is increasing. Aquaculture of seaweed and mussel can provide substantial mariculture product, meanwhile, artificial cultural structure can have ecosystem effects. Using spatio-temporal fish, amphipod and seaweed community monitoring and hydrodynamic simulation-stable isotope analysis-based biodeposit tracing, we compared the fish community structure in raft cultural habitat and adjacent habitat, quantified the correlation between amphipod abundance, biomass and seaweed

biomass and diversity, and assessed the sedimentation effect caused by mussel farming biodeposit s to the adjacent natural seaweed bed habitat of one of Chinese largest mussel cultural habitat – Gouqi mussel farming area in Zhoushan Archipelago, East China Sea, China. Our analysis found that mussel farming habitat have higher diversity and biomass of fish community than adjacent habitats; and increases seaweed community were the dominant factor associated with the abundance of amphipod, one of the key prey species of the fish; however, the biodeposit produced by mussel may caused the degradation of adjacent natural seaweed bed degradation in certain limit area. Our results represent crucial evidence that artificial cultural structure have great potential for marine ranching, but it need comprehensive management and marine spatial planning.

Effects of Translocation of Clams in Small Spatial Scales

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Manila clam *Ruditapes philippinarum* is a commercially important species in Japan, but its landings have been decreased drastically. Releasing live juvenile clams that are imported from other countries has been implemented in many localities to increase the landings, but such efforts have led to other problems such as the introduction of alien species. Here, we conducted a pilot translocation of wild clams around tidal flats in Matsukawaura lagoon, Japan, in order to increase the natural production. We transferred clams in two spatial scales of 100 m and 1 km. The growth of clams was greater in translocated groups, indicating the effectiveness of translocation as a potential tool of enhancing clam production.