May 15, 2020

Spring 2020
Quarterly Science Summaries

Developed by the California Ocean Science Trust for the California Ocean Protection Council

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TOPIC 1: Kelp Recovery

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Executive Summary

- Remote sensing may be a useful tool at this time to support tracking of kelp forest recovery projects' success in California
- Different kelp species with different life cycles have varying sensitivity to climate variability and marine heat waves
- Assisted recovery (e.g., urchin culling, turf algae removal) limited by resource constraints
- Active restoration limited in spatial scalability due to reliance on ongoing transplantation
- Decision-support tools for kelp restoration available from Australia, accounting for resource constraints as well as drivers of kelp forest decline
- "Future-proofing" kelp restoration by identifying warm water-tolerant seaweed genotypes is underway and will need to be part of the kelp restoration portfolio
- "Green gravel" option for outplanting kelp has shown success and offers a cheap, simple, and non-technical deployment solution that may be useful to try in a pilot study in California
- Hypoxic conditions, more than ocean acidification, lead to decline in grazing by invertebrates on juvenile *Macrocystis pyrifera*
- When the invasive *S. horneri* alga was removed in a Southern California experiment, *Macrocystis pyrifera* in the area saw remarkable growth, providing insights into future initiatives on invasive species removal to support kelp restoration

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Summaries

Paper 1: Hamilton SL, Bell TW, Watson JR, Grorud-Colvert KA, Menge BA (**2020**) **Remote sensing: generation of long-term kelp bed data sets for evaluation of impacts of climatic variation.** *Ecology* 0(0), e03031, DOI: 10.1002/ecy.3031

Summary: Long-term (35-year) remote sensing analysis of Landsat images from Oregon and California reveals new insights into kelp responses to climate change trends. Kelp populations with different life histories, even if they're the same species, could respond differently to climate-related variability. *Nereocystis* in Oregon didn't respond to the 2014 marine heat wave (MHW) but even increased in area relative to pre-2014 levels. At the same time, *Nereocystis* populations were decimated in California after the heat wave which resulted in increase in urchin densities. Opposite to *Macrocystis pyrifera*, *Nereocystis* seems positively correlated to winter wave height and negatively correlated with nitrate levels.

Why is this significant? Particularly in a COVID19 and post-COVID19 research era, field work and monitoring may be hindered by stay-at-home and social distancing rules. However, remote sensing coupled with pre-existing ground-truthing information may be very useful at this time and throughout 2020 for better understanding kelp forest dynamics in California and especially would be helpful for any efforts attempting to evaluate the success of pre-COVID19 kelp forest restoration activities.

Paper 2: Layton C, Coleman MA, Marzinelli EM, Steinberg PD, Swearer SE, Verges A, Wernberg T, Johnson CR (**2020**) **Kelp Forest Restoration in Australia**. *Frontiers in Marine Science* 7:74, DOI: 10.3389/fmars.2020.00074

Summary: This paper provides a decision-support tool for kelp restoration (**Figure 1**); this tool has been informed by global work, but has been developed in Australia. In essence, the challenges of kelp restoration emphasize the importance of management effort in protecting existing kelp forests.

Kelp restoration and aquaculture can be cornerstones of future blue economy applications, including for human food, livestock feed, biofuel, and pharmaceuticals, while also bolstering coastal defenses to storm surge. Two strategies in kelp restoration: 1) **assisted recovery** and 2) **active restoration**. 1) Assisted recovery, including culling of sea urchins or installations of substrates for kelp fastening (artificial reefs), have provided short-term success, but results are highly variable and often limited by resource constraints. With some kelp species, e.g., *E.radiata*, urchin removal didn't work; kelp spores didn't results in reestablishment likely due to inhibition from turf algae and sedimentation in the absence of adult kelp; but that species was able to naturally recover when turf algae were removed. 2) Active restoration efforts have better success more frequently, using transplants of juvenile or adult kelp from a donor site or outplanting lab-cultured kelp. Success of active restoration is also naturally cost-prohibitive because it depends on continued transplantation of kelp or quick jump-start (i.e., adequate) natural recruitment of juvenile kelp in the restored site. Outplanting has been more successful when both juvenile and adult kelp are transplanted, likely due to increased predation of juvenile kelp by fish and other stressors in the absence of adult kelp. In Tasmania, Australia, an activer restoration project for *Macrocystis pyrifera* which employed various strategies ultimately yielded inconclusive results and had wide variation in results across 10+ sites. But the study highlighted that outside of Sydney, a project was successful in restoring forests of crayweed (*P. comosa*); the costs for this effort were **$570/m2**. Cost estimates for assisted recovery techniques (urchin culling) come to **$980K for 1km2** over the course of nearly 2 years. Research in Australia now is looking at "future-proofing" kelp restoration by identifying warm water-tolerant seaweed genotypes.

Why is this significant? The decision-support tool presented in this study could help guide decisions and investments in kelp protection and restoration in California. Additionally, the analysis presented here invites California decision-makers and managers to consider what "future-proofing" kelp forest habitats with warmer tolerant species would look like.

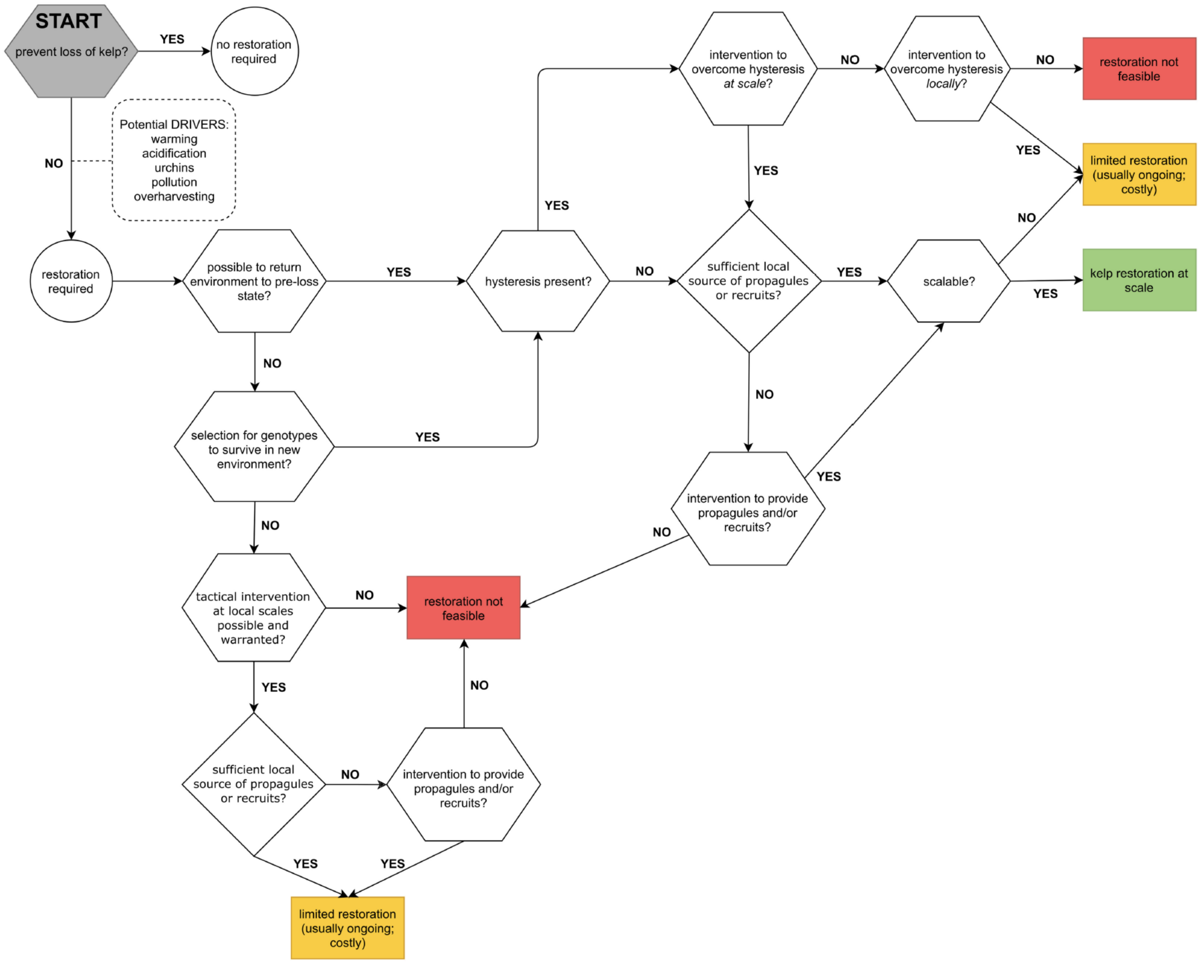

Figure 1. Workflow and decision framework for kelp forest restoration (Leyton et al. 2020).

Paper 3: Fredriksen S, Filbee-Dexter K, Norderhaug KM, Steen H, Bodvin T, Coleman MA, Moy F, Wernberg T (2020) **Green gravel: a novel restoration tool to combat kelp forest decline.** *Nature Scientific Reports*, DOI: 10.1038/s41598-020-60553-x

Summary: "Green gravel" is when small rocks are seeded with kelp and reared in the lab until 2-3cm, and then outplanted in the field. This study did such an experiment with sugar kelp (*Saccharina latissima*) in southern Norway and had high survival and growth over 9 month even when the "green gravel" was dropped from the water surface rather than placed on the bottom/substrate. The technique is simple and cost-effective (**$7 per square meter of recovered reef**!) and can be done without scuba equipment or highly trained people. Scaling up to bigger areas is feasible, as is the potential introduction of more resilient kelp species to new areas which are vulnerable. The "green gravel" method hasn't yet been tested in settings of high grazing pressure or high wave action.

Why is this significant? "Green gravel" could be a good way to overcome some of the current limitations in kelp restoration in California and elsewhere and presents a cheap and simple option worth considering for a pilot project. Different methods of kelp restoration were also compared in this study, along with their associated costs; this could be useful for planning and investments in California (**Figure 2**).

		Green gravel	Ex situ recruitment enhancement[23,25]	Direct seeding[25]	Transplantation[29,34]	Local herbivore removals[19,20,48–50]	Artificial reefs[22]	Protected areas, fishing & water quality regulation[17,51]
DRIVERS & FEEDBACKS	Overcomes substrate limitation	+	+	-	-	-	+	-
	Overcomes propagule limitation	+	+	+	+	-	-	-
	Effective against top down drivers (herbivores)	-	-	-	-	+	-	+
	Effective against bottom up drivers (water quality)	-	-	-	-	-	-	+
	Addition of resilient genotypes	+	+	+	+	-	-	-
	Propagation of resilient genotypes	+	+	-	-	-	-	-
APPLICATIONS	Scalable to large areas	+	?	-	-	+	-	+
	Does not require scuba diving	+	-	-	-	-	+	+
	History of use	-	-	-	+	+	+	+
	Cost (USD m^{-2})	7	118[25]	48[25]	6-160[34]	2[35]	8[34]	?

Figure 2. Comparison of different kelp restoration methods and costs, as well as the benefits from different methods (Fredriksen et al. 2020).

Paper 4: Ng CA, Micheli F (2020) Short-term effects of hypoxia are more important than effects of ocean acidification on grazing interactions with juvenile giant kelp (*Macrocystis pyrifera*). *Nature Scientific Reports* DOI: 10.1038/s41598-020-62294-3

Summary: Grazing impacts on early kelp life stages especially in climate change conditions have not been studied very much, and this is an initial study into this aspect. Lab experiments simulating how four common grazers (of the following taxa: Amphipoda, Isopoda, Gastropoda, Echinoidea) do with juvenile kelp under hypoxia and ocean acidification simulated conditions found that grazing could remove 15-74% of juvenile kelp per square meter in a day. Interestingly, the short-term hypoxic conditions simulated led to lower impact on the kelp, as grazing went down from 15% to 4% per square meter per day. Hypoxia had stronger effects than ocean acidification, weakening grazing on short timescales.

Why is this significant? This study demonstrates that juvenile kelp are particularly vulnerable to grazing by small grazers. But kelp restoration projects may benefit from this study's insights as outplanted juvenile kelp may possibly be well positioned to survive even during hypoxic episodes.

Paper 5: Sullaway GH, Edwards MS (2020) Impacts of the non-native alga *Sargassum horneri* on benthic community production in a California kelp forest. *Marine Ecology Progress Series* 637: 45-57, DOI: 10.3354/meps13231

Summary: *S. horneri* is an invasive species in Baja Peninsula and the Southern California Bight and threatens kelp forest resilience. A *S. horneri* controlled removal experiment in the field showed a 4-fold increase in *Macrocystis pyrifera* recruitment and a 9-fold increase in *M.pyrifera* stipe density. But no measurable change otherwise in net community production. It appears *S. horneri* isn't a driver of an ecosystem change but rather a sign that the ecosystem is disturbed, and it is possible to increase native kelp species abundance back by removing the non-native species.

Why is this important? Studies like this can help inform the timing of invasive and non-native species removal in kelp forests in order to maximize recovery potential for kelp beds.

TOPIC 2: Microplastics

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Executive Summary

Characterizing risk is the last step in risk assessments, and such characterizations are typically completed by combining exposure and effects. Simple calculations, such as estimating the ratio of ambient microplastic concentrations to known thresholds at which species are expected to experience adverse effects, are common. While microplastic detection may need to improve, estimating microplastic exposure seems to be more straightforward. Estimating effects, on the other hand, especially ecologically-relevant thresholds, is less advanced. Determining these thresholds, particularly at the community level, have proven difficult due to a variety of factors, including: diversity in microplastic shape and size, disentangling physical from chemical effects, and lack of data. These studies also suggest that diversity in life history characteristics and behavior could add to difficulties in estimating community-level thresholds. In the course of conducting risk assessments, these findings support the need to clearly define the problem (i.e. sources, pathways, and key ecological components) at the outset of the assessment, and adequately address uncertainty around expected effects.

Summaries

Paper 1: Everaert, G., Cauwnberghe, L. V., Rijcke, M. D., Koelmans, A. A., Mees, J., Vandegehuchte, M., and C. R. Janssen. 2018. **Risk assessment of microplastics in the ocean: modelling approach and first conclusions.** *Environmental Pollution*. 242: 1930 - 1938.

Summary: This study conducted an environmental risk assessment for marine microplastics by estimating past, present, and future concentrations based on trends in global plastic production. To characterize potential risk, the study related exposure and effect assessments by estimating the ratio (RCR) of the predicted ambient microplastic concentrations to the microplastic concentration at which they expected to see no physical effects to marine organisms. The study expects a 50-fold increase in marine microplastic concentrations, and no direct effects of free-floating microplastics by 2100 (i.e. RCR below 1). In contrast, the study predicted adverse ecological effects (RCR above 1) along coastlines, as early as mid-21st century.

Why is this significant? Despite poor data quality, this paper provides a simple risk characterization method. To reduce this uncertainty and improve risk characterization, more data is required to better understand at what concentrations (i.e. ecologically-relevant thresholds) communities are likely to experience adverse effects.

Paper 2: Besseling, E., Redondo-Hasselerharm, P., Foekema, E. M. and A. A. Koelmans. 2018. **Quantifying ecological risks of aquatic micro- and nanoplastic.** *Critical Reviews in Environmental Science and Technology*. 49(1).

Summary: This study reviews information on microplastic occurrence, measurement, modeling approaches, fate, exposure, effects and effect thresholds to conduct a risk assessment. The study assesses a worst case scenario based on the highest reported microplastic concentrations. The risk assessment was conducted by (1) assessing expected exposure, using exposure models, (2) assessing reported effect thresholds, (3) assessing community-level effect thresholds, and (5) comparing exposure and effect to characterize risk. Similar to Everaert et al. 2018, this study found aquatic species in coastal surface waters could be at risk from microplastics. Review of the literature suggests current scientific methods are able to assess microplastic occurrence, single-species effects, and hazards. Yet, more data on effect thresholds are needed to better assess potential risk. There is a clear need to disentangle physical from chemical effects.

Why is this significant? This study demonstrates and provides potential methods, data, and tools to assess exposure with confidence. However, future microplastic risk characterizations will continue to be limited by the uncertainty of effect assessments, at the community level.

Paper 3: Coverton, G. A., Pearce, C. M., Gurney-Smith, H. J., Chastain, S. G. Ross, P. S., Dower, J. F., S. E. Dudas. 2019. **Size and shape matter: a preliminary analysis of microplastic sampling technique in seawater studies with implications for ecological risk assessment**. *Science of the Total Environment*. 667: 124-132.

Summary: Studies use a variety of sampling techniques with varying mesh sizes and sampling volume to detect microplastics particles, raising questions on how much effort (in volume) and what mesh size should be used to accurately detect microfibers in seawater. This study compared two sampling methods (1-liter jars filtered through 8 um vs 10-liter buckets filtered through 63 um) to detect microplastics, and investigated the relationship between mesh size and microplastic concentrations reported in the literature. Researchers found smaller jar samples yield 8.5 times more particles than large bucket samples per L of water. The literature suggests using 300-350 um mesh could underestimate microplastic concentrations by 1 to 4 orders of magnitude.

Why is this significant? Studies commonly use 300-350 um mesh size to sample microplastics. However, the majority of fibers and particles ingested by marine invertebrates and fish are <300 um. This study suggests previous studies may underestimate exposure, and subsequently risk, of marine organisms to microplastics that are ecologically- and biologically-relevant.

Paper 4: Walkinsaw, C., Lindeque, P. K., Thompson, R., Tolhurst, T., and M. Cole. 2020. **Microplastics and seafood: lower trophic organisms at highest risk of contamination.** *Ecotoxicology and Environmental Safety.* (190) 110066

Summary: Research is lacking on the potential for microplastics to transfer to higher trophic levels (i.e. biomagnification). This review evaluated available data on microplastic content within commercially-important species (i.e. fish, shellfish, crustaceans, and macroalgae) at varying trophic levels. The review found species at lower trophic levels are more likely to be contaminated by microplastics than those at higher trophic levels (i.e. apex predators). Interestingly, microplastic contamination (particles/g of wet weight) and mean mercury concentration (ppm) had opposite relationships with increasing trophic level, with microplastic contamination decreasing and mercury concentration increase with trophic level.

Why is this significant? This study suggests lower trophic levels may be at higher risk from microplastics, both physical and chemical. However, while higher trophic species may accumulate fewer physical particles, they do not face zero risk from additives and contaminants. When developing a risk assessment framework, such differences in life history characteristics (i.e. trophic level and feeding strategies) may facilitate specific microplastic pathways and influence if and how species are affected.

Paper 5: Talley, T. S., Venuti, N., R. Whelan. 2020. **Natural history matters: plastics in estuarine fish and sediments at the mouth of an urban watershed**. *PLoS ONE.* 15(3): e0229777.

Summary: This study investigated the prevalence of microplastics in benthic sediments and fish, and whether fish selectively ingested certain types of microplastic particles. Nearly 25% of fish contained small plastics, but prevalence varied with size and between species. Fish species selectively ingested 10 different particle types (colors and forms) within sediments, but selective ingestion varied by trophic level and feeding strategy. Anecdotally, microplastic particles ingested by fish often resemble prey, similar in color and morphology. Fish that normally consume fish eggs preferred microbeads, while fish that normally target filamentous algae, oligochaetes, and nematodes, preferentially ingested synthetic fibers.

Why is this significant? By observing selective microplastic ingestion, this study highlights the need to carefully structure risk assessments according to the behavior of key ecological components (i.e. species, habitats, ecosystems). In this case, understanding foraging behavior can help risk assessors better understand which species may be at risk from particular sources, pathways, and particle content.

TOPIC 3: Economic Analysis of Sea Level Rise

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Executive Summary

- The economics of sea level rise - like the economics of climate change - are still at a formative stage. First estimates of damages have been estimated the rough magnitude of the problem, but there is much work to be done on improving estimates alongside adaptation decision-making, and estimating the distribution of impacts across areas and socioeconomic groups.
- Specific estimations of the economic impact of sea level rise tend to be vague - most often driven by simplified calculations (or assumptions) of economic value.
- Multiple studies are now finding that the economic loss resulting from future sea level rise scenarios increase at a more rapid pace than physical sea level rise projections - in other words, economic damage does not scale with sea level rise linearly.
- Combining standard economic tools (e.g. cost-benefit analysis) with novel sea level rise adaptation thinking (e.g. adaptation pathways) can potentially yield increased economic efficiency of sea level rise decisions, while simultaneously maintaining future flexibility as impacts and scenarios become increasingly understood.
- Many economics papers in this area stress the importance of including dynamic adaptation in future loss models - in other words, damages and costs are likely to be overestimated if human behavior and adaptation is not included.
- There is still considerable disagreement in the literature on the extent to which sea level rise risk is properly and consistently capitalized in real estate values - which has significant implications for future economic damage estimates.
- Shoreline infrastructure replacement value for the Southern California Bight area alone is estimated to be billions of dollars and could displace 100,000 people.

Summaries

Paper 1: Erikson, L.H., Barnard, P.L., O'Neill, A.C., Wood, N., Jones, J., Finzi-Hart, J., Vitousek, S., Limber, P.W., Fitzgibbon, M., Hayden, M., Lovering, J. and Foxgrover, A.C., 2018. **Projected 21st Century coastal flooding in the Southern California Bight. Part 2: tools for assessing climate change driven coastal hazards and socio-economic impacts.** Journal of Marine Science and Engineering, Volume 6 (Issue 3), Article 76, 19 pp., http://dx.doi.org/10.3390/jmse6030076

Summary: This analysis presents the latest iteration of the CoSMoS model (Coastal Storm Modeling System), applied in this paper to Southern California. CoSMoS quantifies physical hazards and socio-economic hazard exposure in coastal zones affected by sea-level rise and changing coastal storms. The socio-economic impact estimations found 25–200 cm of SLR places ~20,000–164,000 residents at risk of being permanently flooded along the Southern California shores. Building replacement values are estimated to be between $3.64 billion and $26.10 billion (2006 value, unadjusted for inflation). Accounting for 100-year storms exposes an additional 56–109% of residents and increases building replacement costs by 46% to $38.2 billion, thus highlighting the importance of including storms in vulnerability assessments and not artificially separating out individual stressors.

Why is this significant? CoSMoS is a standardized modeling approach to quantifying coastal hazard risk, developed primarily by the U.S. Geological Survey (among others). Few studies account for the local-scale effects of SLR and storm-driven coastal flooding across vast geographic areas, and even fewer project the resulting exposure hazards and socio-economic impacts. CoSMoS, now in its third iteration, was thus developed to provide planners, managers, policy-makers, and engineers with local-scale (approximately 10–100 m) data on probable future coastal exposure hazards across large geographic scales (approximately one hundred to several thousand kilometers). Results of the modeled hazards are presented and conjoined with land cover, population statistics, and socio-economic data to provide hazard-exposure estimates along the largely developed Southern California coastline, a region that contributes more than 50% of California's Gross Domestic Product (GDP). The estimates from this study are thus indicative of the likely socio-economic impacts sea level rise will produce along the California coast.

Paper 2: de Ruig, L.T., Barnard, P.L., Botzen, W.J.W., Grifman, P., Finzi-Hart, J., de Moel, H., Sadrpour, N. and Aerts, J.C.J.H., 2019. **An economic evaluation of adaptation pathways in coastal mega cities: an illustration for Los Angeles.** Science of the Total Environment, Volume 678, p. 647-659, https://doi.org/10.1016/j.scitotenv.2019.04.308

Summary: "Adaptation pathways" is a novel approach to climate adaptation decision-making that aims to allow for flexibility among policies to maximize responsiveness to changing risk and uncertainty, potentially spreading adaptation costs over time. This study uses Los Angeles county sea level rise scenarios as an illustrative major metropolitan area and combines a cost-benefit analysis approach with the concept of adaptation pathways. Adaptation pathways were found to have the potential to improve economic efficiency up to 10% in net-present values, compared to implementing a single adaptation strategy. Results also reveal that climate adaptation strategies with nature-based adaptation strategies at their core (restoring dunes, strengthening sandy beaches) are economically attractive for reducing the risks of sea level rise.

Why is this significant? Many economic appraisal tools have been developed to support policy makers with adaptation decisions, but these often have limitations in coping with climate change uncertainty and often are constrained by data limitations. The framework presented here allows for the assessment of triggers that indicate if a pathway transition is economically efficient. It also allows for early investment in adaptation, while maintaining future flexibility as risks and costs are better understood. This approach can better inform decision makers about the robustness and economic desirability of their investment choices. The flexibility of adaptation pathways presents the possibility of making early investments in adaptation and keeping options open to increase protection standards in the future, while maintaining economic efficiency.

Related paper: Kapetas, Leon & Fenner, Richard. (2020). **Integrating blue-green and grey infrastructure through an adaptation pathways approach to surface water flooding.** Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 378. 20190204. 10.1098/rsta.2019.0204.
This paper utilizes an adaptation pathways structure to explore the correct investment mix of green vs. grey flood mitigation infrastructure.

Paper 3: M, Böttle & Rybski, Diego & Kropp, Jürgen. (2016). **Quantifying the effect of sea level rise and flood defence – A point process perspective on coastal flood damage.** Natural Hazards and Earth System Sciences. 16. 559–576. 10.5194/nhess-16-559-2016.

Summary: This paper employs alternative statistical approaches for estimating an "economic damage function" based on extreme sea level rise levels to estimate annual damage, rather than more simplified approaches typically employed in physical science-driven economic damage estimates. This function in part relies on parameterization from extreme damage events, and thus annual economic damages are found to increase as average sea level rise increases - and in fact, losses appear to always increase at a higher rate than the sea levels rise. Because a reliable characterization of sea level extremes is essential for a systematic assessment of climate change impacts due to sea level rise, the authors note the importance of high resolution sea level monitoring efforts.

Why is this significant? This paper serves as an illustration of a detailed economic value estimate for sea level rise damage, in contrast to the more simplified economic estimate approaches found in many sea level rise analyses. Due to the stochastic nature of extreme flooding events, the economic damage associated with sea level rise cannot be predicted for a specific year and is generally estimated by an average value over a longer period of time, making estimates crude. In reality, the actual damage in a given year fluctuates around this "expected" annual damage - for example, there are years without any damage and others where a 1000-year event occurs. This paper employs alternative statistical approaches for estimating a "damage function" based on extreme sea level rise levels to estimate annual damage. The resulting functions and applied case study (Copenhagen) illustrate both the higher degree of specificity possible in economic damage estimates, as well as the way in which findings applicable across specific cities or regions can be found when the economic analysis is based on more than static parameters (e.g. a simple calculation of coastal asset values).

Paper 4: Kubo, Takahiro & Uryu, Shinya & Yamano, Hiroya & Tsuge, Takahiro & Yamakita, Takehisa & Shirayama, Yoshihisa. (2020). **Mobile phone network data reveal nationwide economic value of coastal tourism under climate change.** Tourism Management. 77. 10.1016/j.tourman.2019.104010.

Summary: This paper utilized mobile phone network data to estimate coastal tourism values associated with coastal beaches across Japan, and projected the changing tourism values under climate change by integrating projected beach loss scenarios. The mobile data allowed the researchers to estimate a fine-grained travel cost estimate, which estimates a monetary value per visit per person at each beach. Compared to today's estimated economic values, the projected economic values are less than a quarter under the RCP2.6 scenario, and become smaller as the climate scenarios worsen - reaching less than one-tenth for the RCP8.5 scenario. The value loss rates are substantially more significant than the physical loss rate, implying that without considering social-value weights, policymaking driven by physical change modeling alone would underestimate the impacts of coastal beach loss caused by climate change.

Why is this significant? There is limited fine-grained projection of human response / human dimensions impacts resulting from climate change, which has prevented adaptation policymaking. By utilizing actual human behavior to uncover how much tourists are willing to spend to travel to beaches, the true (social) economic value of each beach was uncovered. This in turn allowed the authors to estimate changes in values based on projected physical changes to the beaches, providing an estimate for value loss of future climate scenarios based on human use value, rather than physical assets.

Paper 5: Justin Murfin, Matthew Spiegel, **Is the Risk of Sea Level Rise Capitalized in Residential Real Estate?**, The Review of Financial Studies, Volume 33, Issue 3, March 2020, Pages 1217–1255, https://doi.org/10.1093/rfs/hhz134

Summary: This paper explores whether recent residential real estate transaction prices capitalize sea level rise risk projections. The study is careful to disentangle price effects that could be confounded with sea level rise - such as elevation, closeness to shoreline, etc. - by exploiting variation in predicted sea level rise rates in 23 coastal states. The study finds zero price effect (through the end of 2017) resulting from sea level rise risk, implying residential real estate values do not currently take into account projected sea level rise impacts.

Why is this significant? This paper is important for several reasons. First, the finding that real estate value estimates do not capitalize sea level rise risk has strong implications for the uncertainty surrounding projected sea level rise economic damage estimates. Second, this finding may imply that consumers either a) have strong skepticism (or are unaware) of sea level rise forecasts, and/or b) that there is confidence amongst consumers in sea level rise mitigation technologies and policies. And third, this study discusses other recent findings that seem to find the opposite conclusion - that sea level rise risk does have a market price effect. The authors estimate that some of this disagreement stems from other studies' inability to separate (for example) confounding effects of elevation and sea level rise risk, but suggest there is also likely correlation between different populations' exposure and belief in sea level rise, meaning price effects could fail to manifest in the properties most likely to face real risk. Overall, however, this study confirms there is still considerable disagreement in the literature of the extent to which sea level rise risk is properly and consistently capitalized in real estate values.

TOPIC 4: Carbon Sequestration of Submerged Aquatic Vegetation

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Executive Summary

- As carbon markets grow in California and nationally, there may be more opportunities for the state to consider coastal wetlands (seagrass, salt marsh) in carbon offset markets; existing wetlands methodologies exist to build upon
- Blue carbon knowledge gaps have been well document; filling these can give the state a jump start on blue carbon applications as California seeks to meet its climate change and carbon neutrality goals via nature-based solutions
- Effectively monitoring blue carbon ecosystems at large scales remains a challenge (in CA, spatial extent of seagrass habitats has remained a major data gap); remote sensing combined with state-of-the-art machine learning may be a cost-effective monitoring technique to explore or advance
- Quantifying total carbon stocks across the state is a first step in assessing the extent of potential blue carbon services in California; methods deployed in the Pacific Northwest may be a good model for California to emulate
- It has been proposed that the carbon capturing role of growing and harvesting macroalgae can be harnessed to locally remediate ocean and coastal acidification; emerging research (unpublished) indicates that cultivation of kelp together with shellfish production may be a beneficial strategy for reducing OA stress

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Summaries

Paper 1: Sapkota, Y, White, JR (2020) **Carbon offset market methodologies applicable for coastal wetland restoration and conservation in the United States: A review.** *Science for the Total Environment*, DOI: https://doi.org/10.1016/j.scitotenv.2019.134497

Summary: The incentive for emission reductions, referred to as carbon offsets, is well established for other ecosystems like forestry and agriculture. Currently, four wetland carbon offset methodologies have been approved in the voluntary carbon market; however to date, few wetland restoration carbon offsets in the US have been transacted. While this carbon offset is in the early stages, this review may help the inclusion of carbon offset components in the coastal restoration and conservation projects in the United States and potentially across the globe.

Why is this significant? As carbon markets grow, there may be opportunities for the state to expand funding streams for wetlands restoration activities. This review summarizes existing carbon offset methodologies for wetland restoration and conservation and provides future steps for considering coastal wetlands in carbon offset markets.

Paper 2: Macreadie, P.I., Anton, A., Raven, J.A. et al. (2019) **The future of Blue Carbon science.** *Nat Commun* 10, 3998. https://doi.org/10.1038/s41467-019-11693-w

Summary: This overview provides a comprehensive road map for the coming decades on future research in blue carbon science. It gathered many leading blue carbon experts in the field to agree upon the top-ten pending questions in blue carbon science. Top priorities include (1) understanding how climate change affects carbon accumulation in mature blue carbon ecosystems and during their restoration; (2) the role of carbonate and macroalgae in BC cycling, and the degree to which greenhouse gases are released following disturbance of BC ecosystems; (3) improved precision of the extent of blue carbon ecosystems; (4) advancement of techniques to determine blue carbon provenance; (5) understanding of the factors that influence sequestration in BC ecosystems, with the corresponding value of BC; and (6) the management actions that are effective in enhancing this value.

Why is this significant? As California seeks to meet its climate change and carbon neutrality goals, there is likely to be more interest in nature-based solutions that capture and store carbon in oceans and coastal ecosystems. Filling knowledge gaps identified here can give the state a jump start on blue carbon applications.

Paper 3: Serrano, O., Kelleway, J. J., Lovelock, C., & Lavery, P. S. (2019). Conservation of Blue Carbon Ecosystems for Climate Change Mitigation and Adaptation. In *Coastal Wetlands* (pp. 965-996). Elsevier. https://doi.org/10.1016/B978-0-444-63893-9.00028-9

Summary: This book chapter provides a good primer on blue carbon systems within a global context. It covers the ecology of blue carbon, carbon cycling, factors that influence carbon storage, and case studies for conservation and restoration of blue carbon ecosystems as a strategy for climate change mitigation and adaptation.

Why is this significant? Knowledge of the role of natural ecosystems in capturing and storing CO_2 is an increasingly important component in developing strategies to mitigate climate change associated with anthropogenic inputs of CO_2 to the earth's atmosphere.

Paper 4: Pham, T.D.; Xia, J.; Ha, N.T.; Bui, D.T.; Le, N.N.; Tekeuchi, W. A Review of Remote Sensing Approaches for Monitoring Blue Carbon Ecosystems: Mangroves, Seagrasses and Salt Marshes during 2010–2018. *Sensors* **2019**, *19*, 1933. https://doi.org/10.3390/s19081933

Summary: Remote sensing-based approaches have been proven effective for mapping and monitoring blue ecosystems by a large number of studies. This is the first comprehensive review on the applications of remote sensing techniques for mapping and monitoring blue carbon ecosystems, providing an overview of key studies undertaken from 2010 onwards. The study finds that optical imagery, such as multispectral and hyper-spectral data, is the most common for mapping blue carbon ecosystems, while the Landsat time-series are the most widely-used data for monitoring their changes on larger scales. The paper investigates the limitations of current studies and suggests several key aspects for future applications of remote sensing combined with state-of-the-art machine learning techniques for mapping coastal vegetation and monitoring their extents and changes.

Why is this significant? Effectively monitoring blue carbon ecosystems at large scales remains a challenge owing to practical difficulties in monitoring and the time-consuming field measurement approaches used. In California, mapping the spatial extent of seagrass habitats has remained a major data gap for assessing the potential role of seagrass as a blue carbon habitat.

Paper 5: Kaufmann, BJ, Giovanonni, L, Kelly, J, Dunstan, N, Borde, A, Diefenderfer, H, Cornu, C, Janousek, C, Apple, J, and Brophy, L. **Total ecosystem carbon stocks at the marine-terrestrial interface: Blue carbon of the Pacific Coast, USA.** Global Change Biology (submitted December 2019)

Summary: The coastal ecosystems of temperate North America provide a variety of ecosystem services including values as significant sites of carbon sequestration. Yet, little data exists on the carbon stocks of major tidal wetland types in the Pacific Northwest, USA. To fill this data gap, authors quantified the total ecosystem carbon stocks (TECS) in seagrass, emergent marshes, and forested tidal swamps, occurring along increasing elevation and decreasing salinity gradients in the Pacific Northwest.

Why is this significant? Quantifying total carbon stocks across the state is a first step in assessing the extent of potential blue carbon services in California. The methods deployed in the Pacific Northwest may be a good model for California to emulate.

Paper 6 [*Note: Ongoing research*]: Price, N., Arnold, S., Dobbins, P., Honisch, B., Hunt, C. W., Melendez, M., ... & Shellito, S. (2020, February). **Kelp Farming as a Potential Strategy for Remediating Ocean Acidification and Improving Shellfish Cultivation**. In Ocean Sciences Meeting 2020. AGU.

Summary: Cultivated macroalgae may remove sufficient amounts of CO_2 via primary production to mitigate ocean and coastal acidification at small spatial scales, creating a 'halo' of improved water quality. Mussels (*Mytilus edulis*) grown within the kelp farm had shells with significantly greater acute pressure resistance (75%), higher force tolerances to breakage (5%), greater shell thickness (27%) and density (88%), and larger meat masses (28%). This study provides evidence that co-cultivation can provide a strategy for reducing marine calcifier stress and increasing mussel product quality.

Why is this significant? It has been proposed that the carbon capturing role of growing and harvesting macroalgae can be harnessed to locally remediate ocean and coastal acidification (OCA). This study indicates that cultivation of kelp together with shellfish production may be a beneficial strategy for reducing OA stress.

TOPIC 5: Aquaculture

PDF Folder (here)

Executive summary

- Real-time data of water quality inside shellfish aquaculture operations would greatly help management to adapt quickly to changing water quality conditions, help improve shellfish breeding, harvest and yield
- Climate variability and climate change impacts are key drivers of mussel farms productivity, understanding these patterns will help with site selection, leading to more efficient marine spatial planning
- Remote sensing can be used to estimate surface-water nutrient concentrations, thus supporting site selection for kelp aquaculture in the Southern California Bight
- Kelp aquaculture has the potential to provide an array of ecosystem services and positive impacts to coastal communities in California, such as: mitigation of ocean acidification conditions in surrounding waters, increase food security by using kelp for feed and fertilizer in other aquaculture and agriculture operations, and provide an accessible livelihood to coastal communities requiring little capital investment
- The Ecosystem Assessment of Aquaculture framework could be a useful tool to use in California to assess the potential negative impacts of offshore kelp aquaculture to ensure the sustainability of the industry - using other states effort, like Maine, as examples
- Geographic information systems (GIS) and other spatial planning tools can allow coastal managers, aquaculture applicants and other stakeholders to access spatial information and help guide aquaculture business and regulatory decision-making

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Summaries

Paper 1: Bresnahan et al. (2020) **Equipping smart coasts with marine water quality IoT sensors**. *Results in Engineering 5(100087)*, DOI: 10.1016/j.rineng.2019.100087

Summary: Ocean acidification has been shown to be one of the most important drivers in shellfish mortality, however, carbon chemistry measurements are not always available to aquaculture operations (due to the complexity and costs and the sensors and their maintenance). In this study, researchers from Scripps Institution of Oceanography collaborated with industry representatives of the Carlsbad Aquafarm to obtain real-time carbon chemistry data. They deployed a SeapHOx with a cellular-enabled surface mooring measuring pH, dissolved oxygen, salinity, temperature, and water depth. Researchers were also able to calculate the saturation state of aragonite (ΩAr), using the real time pH measurements from the SeaphOx along with average total alkalinity (measured from discrete samples). As low ΩAr has been shown to have deleterious effects on shellfish growth and larvae survival, carbon chemistry monitoring can help improve timing of shellfish breeding and releases into ambient seawater.

Why is this significant? Real-time data would greatly help management to adapt quickly to changing water quality conditions. This paper can serve as a case study for university and industry collaboration and for the use of cellular mooring for added real-time capabilities.

Paper 2: Sainz JF, Lorenzo ED, Bell TW, Gaines S, Lenihan H, Miller RJ (2019) **Spatial Planning of Marine Aquaculture Under Climate Decadal Variability: A Case Study for Mussel Farms in Southern California**. *Frontiers in Marine Science*, *6*, DOI: 10.3389/fmars.2019.00253

Summary: Using historical environmental data from 1981 to 2008, this study modeled the effects of climate variability on profitability of hypothetical mussel aquaculture operations in the Southern California Bight. Results showed that decadal fluctuations, linked to the phases of the North Pacific Gyre Oscillation (NPGO), had a strong impact on mussels farms profitability both spatially and temporally. The region around Point Conception displayed highest yields and less year to year variation, implying a stable mussel production rate through time and making it a suitable site for a mussel farm. Compared to the North, the central and southern regions of the Southern California Bight showed smaller productivity rates.

Why is this significant? Climate variability and climate change are important drivers of productivity in marine aquaculture, understanding the impact of environmental variability over aquaculture sites is a key component of site selection and will lead to more reliable and efficient marine spatial planning.

Paper 3: Snyder JN, Bell TW, Siegel DA, Nidzieko NJ, Cavanaugh KC (2020) **Sea Surface Temperature Imagery Elucidates Spatiotemporal Nutrient Patterns for Offshore Kelp Aquaculture Siting in the Southern California Bight.** Frontier in Marine Science, DOI: 10.3389/fmars.2020.00022

Summary: This study identified sites in the Southern California Bight most suitable for aquaculture of giant kelp (*Macrocystis pyrifera)*. Using satellite imagery of sea-surface temperatures (SST) and *in situ* measurements across seasons, this study estimated surface water nitrate concentrations across the Southern California Bight and used this data to perform a siting analysis of potential kelp aquaculture farms. The siting analysis found that estimated nitrate concentrations followed expected nutrient patterns within the Southern California Bight, with high nitrate concentrations in the north and west due to spring upwelling and low concentrations in the southeast area (see Figure 3). The siting analysis also identified the western Santa Barbara Channel as an ideal site for offshore kelp aquaculture, with high nutrient concentration capable to support year-round growth of kelp.

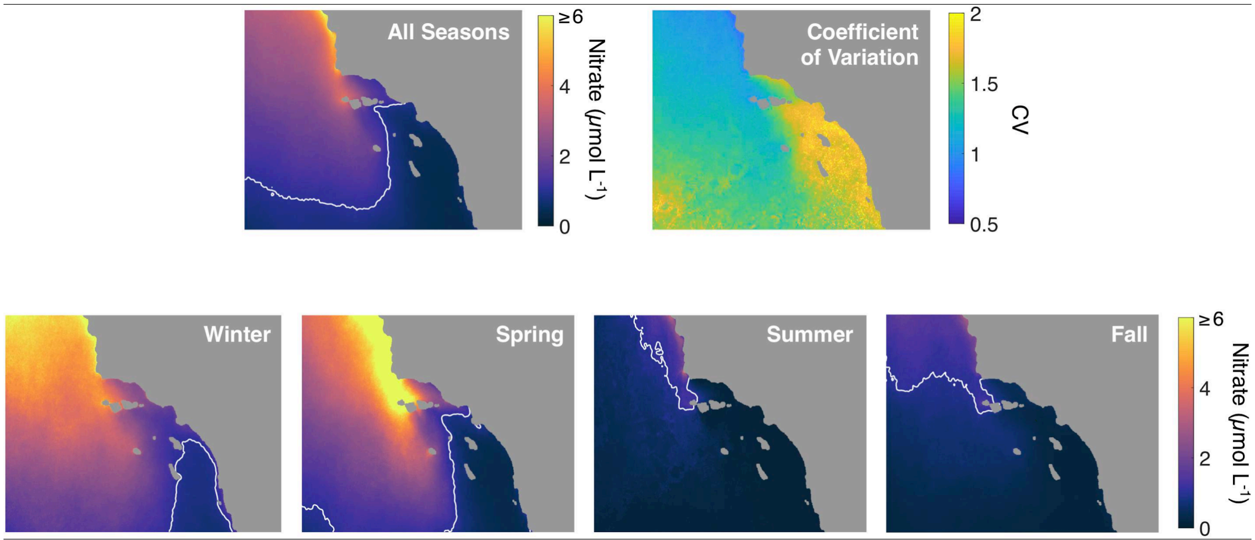

Figure 3. Top row: Mean and coefficient of variation (CV) of estimated nitrate concentration over the study area across all seasons. **Bottom row:** Mean estimated nitrate concentration across each season over the study area. White contour line shows the location of the 1 µmol L–1 nitrate concentration front (from Snyder et al. 2020).

Why is this significant? Although the Southern California Bight provides a suitable area for potential offshore kelp aquaculture operations - due to the upwelling of cool nutrient-rich waters capable of supporting large giant kelp populations - nutrient concentrations vary greatly in the area across seasons and can be a limiting factor for kelp growth. It is important to understand the variability of surface water nutrients across space and through time at the appropriate scale in order for offshore kelp aquaculture operations to be successful. The method used in this study resulted in a successful estimate of surface nitrate concentrations using satellite imagery and could be used to help identify other suitable areas for offshore kelp aquaculture along the coast of California.

Paper 4: Grebe GS, Byron CJ, St. Gelais A, Kotowicz DM, Olson TK (2019) **An ecosystem approach to kelp aquaculture in the Americas and Europe**. *Aquaculture Report 15(100215)*, DOI: 10.1016/j.aqrep.2019.100215

Summary: This study used the kelp aquaculture industry in Maine as a case study to model the potential impacts of kelp aquaculture using the Ecosystem Approach to Aquaculture (EAA) document. This framework was developed by the Food and Agriculture Organization of the United Nations (FAO) and is widely used for evaluating aquaculture practices. Out of the 43 originally described issues and impacts in the EAA, 25 were relevant to kelp aquaculture.

Summary of the negative impacts of kelp aquaculture addressed in this study:

- Potential risk for marine mammals entanglement in kelp lines. Although no cases have been reported in Maine so far, this risk could increase as more kelp farms are deployed in other regions
- Concerns around the overharvesting of wild kelp to provide seed sources for aquaculture

- Potential for negative impact of kelp farms on other algae species in nutrient-poor areas. As the kelp industry expands, farmed kelp could start competing for nutrients with other algae in the surrounding environment. Thus, sIte selection for kelp farms should avoid nutrient-poor areas to prevent this impact
- Risk of decreased genetic diversity caused by seed production strategies. Presently, reproductive tissue from 1 or 3 mature individuals is used to produce billions of spores, resulting in enough seeds to supply multiple small farms. This results in individuals of a farm having similar genetic composition. There is then a potential for these individuals to release their genetic material into the surrounding ecosystem and potentially outcompeting wild populations.

Summary of the positive impacts of kelp aquaculture addressed in this study:

- Potential bioremediation role of kelp by removing excessive nutrients, carbon sequestration potential, mitigating ocean acidification - benefiting calcifying organisms - and potentially enhancing cultured shellfish growth.
- Potential habitat contribution - however, more studies are needed to assess this potential and understand the consequences of the loss of habitat after harvest.
- Impacts on food security: kelp can be used as livestock feed or fertilizer, as well as input in other aquaculture systems. For example, kelp has potential for mitigation impacts of animal excrement in integrated multi-trophic aquaculture (IMTA) systems. Kelp can also contribute to human protein and energy requirements, as it is a good source of carbohydrates, fibers and vitamins, and can also be used as probiotics
- Kelp aquaculture is an accessible marine livelihood that can supplement or replace income from existing ocean foods production. Small Scale kelp farming requires little capital investment, which makes it more realizable to newcomers than other forms of aquaculture. Better access and competitiveness within existing markets, and the creation of new markets, will help to solidify kelp aquaculture as an alternative or supplemental livelihood

After identifying the potential impacts and issues linked to kelp aquaculture, the authors identify recommendations for new action, research, and resource management to further ensure the sustainability of kelp aquaculture, such as:.

- Defining the ecosystem and management boundaries for kelp aquaculture to prevent habitat degradation and associated biodiversity losses, productivity declines, and impacts on local communities and other users
- Assess ecosystem services and environmental capacity (referred as the ability of ecosystem services to tolerate a particular activity without unacceptable impact) associated with kelp culture to lessen the potential for habitat degradation and associated biodiversity losses and productivity declines
- Pursue ecologically and socially considerate engineering and marine spatial planning to minimize potential impacts to the viewsheds of local communities and avoiding impact on marine fauna that will become increasingly important as the kelp industry grows
- Protect health and genetic diversity of wild kelp beds
- Develop industry-wide Best Management Practices for seaweed harvesting, management, cultivation

- Develop climate change resiliency by conducting further research kelp physiology and culture methods
- Integrate kelp aquaculture and harvesting into a wild kelp management plan to prevent overharvesting of wild kelp and ensure the sustainability of seed sources.

Why is this significant? There is a lot of interest and potential to cultivate kelp along the coast of California and kelp could provide an array of ecosystem services, ranging from ocean acidification mitigation, increase fisheries productivity, increase food security... However, addressing the environmental and social impacts of kelp farming is critical to ensure the sustainability of the industry. This study could be used as an example to assess the impacts of kelp aquaculture in California, using the EAA framework to assess relevant issues and impacts as well as identifying key stakeholders groups to engage in this effort.

Paper 5: Wickliffe LC, Crothers VC, Theuerkauf SJ, Riley, KL, Morris JA (2019) **Shellfish aquaculture map viewer: an assessment of design, data, and functions to inform planning and siting in the United States.** *Journal of Shellfish Research, 38 (2)*, DOI: 10.2983/035.038.0201

Summary: Shellfish aquaculture provides opportunities for habitat restoration and enhances the economic sustainability of coastal communities. In the United States, two-third (by value) of marine aquaculture production consists of bivalve shellfish (oysters, clams and mussels). The opportunity to expand the shellfish aquaculture industry requires coastal managers to evaluate the industry's fit in the existing coastal, estuarine, and ocean uses. Geographic information systems (GIS) and other spatial planning tools can allow coastal managers, aquaculture applicants and other stakeholders to access spatial information and help guide aquaculture business and regulatory decision-making. This study provides a synthesis of web-based GIS decision support tools (map viewers) to provide guidance for permitting and development of shellfish aquaculture in state waters across the United States. Map viewers act as decision support systems to standardize spatial data for decision-making. Potential spatial interactions, including environmental (e.g., distribution of protected species and sensitive habitats), space–use (e.g., fishing, navigational channels, and oil and gas operations), and general compatibility, are incorporated within these planning tools (Longdill et al. 2008), providing instant access to spatial data.

Why is this significant? While California does not have a shellfish aquaculture map viewer (as of 8/31/2018), investing in this tool could help support sound planning decisions, offer timely risk-based updates to the public, and enhance the likelihood of success of commercial aquaculture management initiatives in California. This study provides recommendations for developing a shellfish aquaculture map viewer, such as:

- Predefined target audience to ensure the tool is most effective and includes useful information and data that are well conveyed
- Definition and discussion with key stakeholders and potential users of the map viewer functionality and data layers before development
- Outlining and defining the need for a map viewer to inform the required level of complexity for a given viewer, the needed data, and the tools available within it

- Predefine relevant data layers to include in the shellfish aquaculture map viewer (see Table 1 for the list)

Layers that were identified as the most necessary and useful data layers to include in a shellfish map viewer, based on analysis and professional knowledge and expertise.

Infrastructure	Shellfish resources*	Oceanographic/biophysical	Biological	Geomorphological
Danger zones and restricted areas	Shellfish riparian leases	Bathymetry or depth contours	Critical habitat	Substrate type
Military operating areas	Shellfish management areas	Surface/bottom salinity	Essential fish habitat (EFH)	Slope factor
Unexploded ordnances	Shellfish suitability areas	Surface/bottom water temperature	Habitat Areas of Particular Concern (HAPC)	
Shipping fairways and ferry pathways	Commercial shellfish-growing areas	Surface/bottom current speed and direction	Marine protected areas (MPAs)	**Cultural**
Energy infrastructure	Closed shellfish areas	Significant wave height	National wetland inventory (NWI)	Tribal resources
Coastal maintained channels	Shellfish patrol areas	Dissolved nutrients (nitrate, phosphate, and silicate)	State reserves	Archaeologically sensitive areas
Anchorage areas and turning basins	Recreational shellfish harvest areas	Chlorophyll *a*	Harmful algal blooms (HAB) type, concentration, and frequency	National marine sanctuaries (NMS)
Marinas and public boat ramps	Closed recreational shellfish harvest areas	Dissolved oxygen	SAV and/or kelp beds	State parks and state beaches
Ocean disposal sites	Shellfish protection districts	Turbidity and light attenuation	303(d) impairments	**Administrative boundaries**
Wastewater treatment outfalls and sewer lines	Public oyster reefs	Freshwater inputs (USGS stream gauges)	Water quality–monitoring stations	Federal/ state waters boundary (SLA)
On-site sewage systems	Oyster material–planting areas	Tidal differential and flushing rates	State or local protected species	State counties
Pipelines and pipeline areas	Existing aquaculture leases	pH	Cetacean Biologically Important Areas (BIA)	NOAA raster nautical chart (RNC)
Submarine cables and areas		1,000-ft-high water mark buffer	Sea turtle home ranges	
Shipwrecks and artificial reefs			Seabird nesting areas	
Fixed fishing devices			Protected species population densities	
AIS vessel density				
Beach nourishment				

Table 1. Most relevant data to include within a shellfish aquaculture map viewer (from Wickliffe et al. 2019)