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Something old, something new: Historical perspectives provide lessons for blue growth agendas

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Total number of authors:
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Published in:
Fish and Fisheries

Link to article, DOI:
10.1111/faf.12460

Publication date:
2020

Document Version
Peer reviewed version

Supplementary materials 1

Table S1. Case study overviews, the positive and negative outcomes and drivers in relation to blue growth, together with lessons for contemporary blue growth agendas. See SOM 2 for case study summaries that provide further details and context. NB: Blue Growth (BG) overarching criteria are (1) achieving growth while minimising environmental impact, (2) maintaining balance, (3) implementing smart solutions and (4) achieving integration.

No.	**Stock, system, or ecosystem service**	**Period**	**Successes in blue growth (BG) context**		**Failures in blue growth (BG) context**		**BG criteria**	**Lessons for Blue Growth (BG)**
			Outcome(s)	**Driver(s)**	**Outcome(s)**	**Driver(s)**		
1	Galway Bay, Ireland: mixed capture fishery	1820s–1860s	*Pre-1850s and pre-trawl:* • Community-based management of fishery • Equitable access • Sustainable use of marine resources	• Local democratic control of resource • Desire for social equity and to retain economic control • Desire to maintain resource sustainability • Local stakeholders' traditional ecological knowledge valued by management regime	*Post-1850s and post-trawl:* • Overexploitation of the resource • Decline in social-economic equity due to power imbalance (trawlers in a financial and practical position to force out non-trawling locals)	• Shift from local to national political control • Desire for economic growth and use of new technology • Local stakeholders' traditional ecological knowledge no longer valued by management regime	(1), (2)	• Importance of stakeholder engagement, value of traditional ecological knowledge • Prioritizing one value (economic growth) over all others can undermine blue growth success • Without appropriate management controls, technological innovation can lead to overexploitation • Failure to understand and address the limits to industry growth has consequences, including system collapse • Benefits to stakeholders from BG may be unequal or incompatible, creating conflict
2	Recreational fisheries, Queensland, Australia – on snapper and other reef-	1870s–onwards	*1870s – present:* • Growth in numbers of recreational fishers *1970s onwards:* • Increasingly responsible fishing practices	• Recreational fishing became increasingly accessible via fishing clubs and tackle stores • Key actors in the fishery and larger community/	*1870s-present:* • Unregulated growth of the fishery • Localised overexploitation of	• Technological advancements • Regulations rarely enforced or ignored (until the 1990s) • Large numbers of recreational fishers created	(1), (2), (4)	• Alignment of top-down (regulation) and bottom-up (societal change) drivers can facilitate sustainable resource use and increase stewardship

	associated fishes		encouraged among recreational fishers • Equitable access • Evidence of increased stewardship and awareness of the need to sustain marine resources	media encouraged cultural shifts among users • Stricter regulations introduced (from 1990s) • Environmental concerns increased conservation mindset nationally, and globally	some fishery resources • Evidence for reactive rather than proactive management regulations	political power/voice that may disproportionately benefit recreational fishers over the short-term only and thus contribute to lower long-term social equity		• Need for integration across spatial scales and different sectors in order to recognise cumulative impacts of activity and effects on blue growth
3	Small-scale fisheries within Lagoon of Venice, Italy (Mediterranea n)	12th–20th century	*12th–18th century*: • Ecosystem-based management of lagoon fishery resources • Preservation of environmental quality alongside sustainable use • Long-term public interests valued over short-term private ones • Balance achieved between the economic freedom of citizens and the protection of shared resources • Stakeholder engagement in management • Equitable access to markets	• Dependence of local communities on fishery resources meant effective management and long-term sustainability were critical for the societal well-being • Strict and enforced regulation of both the fishery and the market • Co-management directly engaged local stakeholders	*19th–early 20th century*: • Overexploitation of the resource • Illegal and destructive practices • Erosion of long-term sustainability goals • Lack of appropriate management	• Political instability of the area due to major changes in governance • Widespread local poverty increased demand for food • Authorities responded to increased demand for food by removing prior regulations, allowing open access to fisheries • Deregulation of fishing and trade, previous co-management strategies abandoned	(1), (2)	• Importance of stakeholder engagement, value of stakeholder knowledge • Importance of top-down and bottom-up controls - strict enforcement for regulatory breaches may be necessary • Regulations that incorporate the whole system (natural and human e.g. markets/trade) produce more sustainable outcomes • Importance of long-term over short-term gains • Relevance of extrinsic drivers and events unrelated to fisheries • Shared ownership of the resources (co-management) and/or direct involvement of fishermen in management facilitates sustainable exploitation • Increased/open access can lead to overexploitation
4	Southern Bluefin Tuna (SBT) aquaculture, South Australia.	1940s–onwards	*1940s and 1950s:* • Investment in ecological knowledge • Privatisation of and individual investment into marginal products (fringe/speculative investment)	• Alignment of institutional and resource user goals: (1) Personal (individual licence holder) desire for economic benefits; (2) Institutional desire for application and capture of economic benefits (within a state)	*1960s to 1980s* • Economic growth failed to be sustainable or to avoid further degradation: (1) Unregulated global growth beyond jurisdictional control	• Increasing market pressure, especially beyond jurisdictional boundaries, ability to increase production and further economic growth • Lack of early and sufficient regulation for a migratory, multi-jurisdictional species	(2), (3), (4)	• Importance of scientific knowledge, monitoring and regulation as new resources and products are developed. • Multi-jurisdictional management (international, national, and state) can be complex, but highly effective at promoting sustainable growth.

			• Product development (canning) *1960s onwards:* • High quality product development (raw product) based on international market • Increased efficiencies in farming (ranching) *1980s onwards:* • Implementation of consistent, rigorous management enabled sustainability even with growth and economic returns	• Economic gains from new 'speculative' products – increased with new technology (e.g. canning) and/or approaches (e.g. aquaculture) • National (state) desire to develop a management framework for achieving ecologically sustainable development for aquaculture • Global overfishing of tuna stocks motivated international intervention.	led to overexploitation • Environmental pressures (actual and perceived) from high intensity farming, requiring regulation and management	• Lack of knowledge about environmental impacts and need for regulation of aquaculture		• Alignment of management and resource user goals can facilitate growth • Relevance of extrinsic drivers, which may have both positive and negative outcomes for growth • Growth opportunities are not linear and can be based on innovation, product and technological development
5	Blue revolution in the Adriatic Sea – Italy 1: aquaculture of species including sea bass and gilt head sea bream	1970s–onwards	*1980s-1990s:* • Increased production alongside economic and social benefits • Increased conservation of semi-natural habitats (sea ponds) • New technologies spread to other areas in the Mediterranean.	• Crisis in global fisheries production aligned with new technological developments created opportunities for growth • Need to sustain local aquaculture and related employment spurred innovation • Economic incentives as well as support from local and national management • Scientific research also supported new production methods in aquaculture, sharply enhancing productivity	*1990s to today*: • Loss of balance between economic and social benefits • Loss of income, employment, traditional stakeholder knowledge	• Local resource dynamics ("rise and fall") had negative economic and social outcomes • Indirect conflicts between local producers and farmers in other countries • Inability of aquaculture sector to adapt or cope with increasing competition from other countries • Lack of vision on the added value of products to alternative and larger markers via trade	(1), (2), (3)	• Importance of top-down management supported by ecological understanding, especially for new products • Importance of time scales: innovation can represent only a short-term benefit • Relevance of extrinsic drivers, especially across space • Potential for research and technological innovation, coupled with economic incentives and effective management, to support new productions and generate economic, social and even environmental positive feedbacks • Importance of sector adaptability to market and environmental change • Spread of technology can have unexpected and unequal

								consequences that may vary in space and change over time • Importance of people valuing ecosystems and habitats
6	Blue revolution in the Adriatic Sea – Italy II: trawling	1910s–1980s	*1920s-1930s:* • 10% of fishers used steam engines to reach fishing grounds but not trawl *1940s-1980s:* • Broad adoption of technological innovation (1950s-1960s), steam engines used to power trawlers and winches used to lift catch • Increase in fishermen's wealth (as a broad category) alongside an increase in landings and economic value of fishing • Large increases in landings from 1940s	• Increasing population led to an increased demand for local fishery production • Competition with other countries encouraged the spread of technological innovation • Spread of welfare systems to fisherman and other social assistance (e.g. pension) protected fishermen's families and wealth • Government experiments (1912) and subsidies (1920s-1980s), to support the adoption of new technologies, reduce costs of loans, for investments in new gear etc.	• *1980s:* Evidence for local depletion of resource became apparent • Overcapacity led to increased fishing pressure and decline in fish stock productivity • Lower income margins for local fishermen • Increase in inequality among fishers (from being mostly poor, those who joined the technological revolution increased their incomes compared to low technology fishers) • Increase in fishing vessel size and thus fishing fleet capacity. • Decrease in the number of vessels and fishermen, e.g. from 3500 to 500 vessels in Chioggia-Venezia	• *1990s onwards:* EU policies started limiting fishing capacity and effort. • Overcapacity of the fleet • Open access to fishing with limited and ineffective regulations • Management did not consider environmental impacts or long-term perspective when setting management objectives	(1), (2), (3)	• Importance of sound scientific research to support appropriate management • Importance of time scales: current success may have consequences in future, especially when adopting new technology • Alignment of human needs, in terms of both products and social systems, and technological advances • Failure to understand and address the limits to industry growth may have consequences, including system collapse • Failure to recognize the limits of ecological systems and in particular to moving beyond their self-regeneration limits; • Planning for blue growth should be addressed within a socio-ecological system approach

7	Dugong fisheries in S Queensland (industrial focus on oil)	1800s–1969	• Small-scale subsistence fishing by Europeans (late 1820s-1830s) • 1840s-1860s rapid, but punctuated, industrial growth (beginning in Moreton Bay and spreading north) • Successful merging of new technology with traditional practices • Equitable access at times • Fishery contributed positively to key periods of social change (establishment of new cities)	• Transfer of traditional knowledge • Importance of fishery for local needs as well as demand from international markets • Collaboration across resource groups	• Failure to grow industry despite potential global demand • Fisheries contracted (1870-80) but exports remained high, followed by decline with fisheries closures between 1859, 1888-1899, 1910-1929 • Overexploitation, stocks have not yet recovered to pre-exploitation levels • Inequitable access and decline of stakeholder engagement • Lost cultural services for indigenous peoples (spiritual & cultural value)	• Inability to maintain consistent supply • Adulteration of product • Failed management and lack of scientific understanding, especially given challenging nature of stock (life history, behaviour) • Technological developments and indigenous resettlement impacted social equity • In 1969 dugong became protected by state law, today permits are issued for indigenous subsistence fishing only	(1), (2)	• Importance of appropriate management supported by ecological knowledge • Importance of stakeholder engagement and valuing of stakeholder knowledge • Importance of multiple drivers beyond economic growth, relevance of extrinsic drivers • Value of fisheries for social change • Failure to understand and address the limits to industry growth may have consequences, including system collapse
8	Southern New England Inshore fisheries, subsistence fishing	1820s–1860s	*1830s-1850s:* • Successful small scale inshore fishery (hook and line) • Food stability for dependent local communities during the development of an unstable manufacturing economy and expansion of cash economy • Equitable access supported by legislation	• Working families need for food, especially to ease insecure employment in the boom and bust of industrial economy • Low start-up costs for access to inshore fisheries	*1850s onwards:* • Unequal access to inshore fishery, focus on commercial growth • Loss of local fishery sustainability • Emigration of fisher's families to seek employment elsewhere (*1890s onwards*)	• Innovation in offshore fisheries (switch to bait fishing) led to the development of an inshore bait fishery • Introduction of pound net created commercial competition for small-scale fishers (who could not afford the capital investment) • The decline of inshore stocks caused social unrest	(1), (2)	• Danger of top-down control focused on a single outcome • Importance of spatial scales: (1) value of marine resources to the larger industrial economy can undermine local sustainability; (2) incompatibility of local needs versus regional markets/needs • Relevance of extrinsic drivers; local economy • Value of fisheries for societal change - e.g. supported the expansion of the manufacturing

						• Political desire to expand commercial fisheries meant management prioritized the interests of commercial over small-scale fisheries		industry. Small scale fisheries can create resilient communities • Importance of long-term over short-term gains, and benefits to wider society over those of a few commercial operators • Technological innovation in one fishery can have unexpected impacts on others
9	Commercial fisheries in Sweden	1910–1995	• Sustainable use alongside social improvements • Increased efficiency of fishing operations • Improved product quality, less waste due to new technologies	• Alignment of social needs (employment and cheap nutrition) encouraged government policies and subsidies to promote industry growth • Technological improvements • Stable resource base	*1960s onwards*: • Overexploitation and declining stocks, loss of profitability • Increased wastage • Loss of equal access	• Fleet overcapacity • Failure to acknowledge natural limits to industry growth • Fishing became unprofitable for some, local small-scale fisheries disappeared • Focus on certain groups in policy formulations prioritized certain commercial fisheries and gains over other goals (e.g. ecosystem health, market supply, equitable access) • Market subsidies encouraged deliberate wasting of fish	(1), (3)	• Policies to encourage growth in the fishing industry were not equitable, led to loss of small-scale fleets. • Policy innovation (e.g. subsidies) may create undesirable outcomes e.g., wastage/feedbacks. • New management regimes/policy goals can fail to address social equity issues • Failure to understand and address the limits to industry growth may have ecological, social and economic consequences, including system collapse
10a	Coral reef social-ecological systems: Main Hawaiian Islands	1400–1819	• Recovery of coral reef communities from prior exploitation alongside the development of large-scale fishpond aquaculture • Sustainable use of resources • Equal access	• Large chiefdoms imposed controls on social consumption of some fauna • Reef conservation strategies were implemented to accommodate aquaculture, agricultural complexes and animal husbandry	• Harvesting and invasive species leading to reductions in abundance of vulnerable marine megafauna	• Arrival of and subsequent exploitation by Polynesian voyagers	(1), (2)	• Appropriate top-down control of resource use supported by ecological understanding can allow recovery *and* growth. • Alignment of management controls and cultural/social customs facilitates growth/recovery • Recognition of connections between marine and terrestrial sectors enables improved sustainable management practices

				• Feudal, common property land system with ecological knowledge • Traditional stakeholder knowledge valued				
10b		1778–1860+	• Initial ecosystem recovery • Development of sustainable commercial fisheries	• Major cultural, societal, and political upheaval due to the arrival of colonists • Re-direction of labour away from traditional fishing practices and towards foreign commercial enterprise (e.g. whaling) • Stochastic events helped ecosystem recovery (e.g. human epidemics, WW2)	• Resource use unsustainable over time • Eventual degradation of reef ecosystems (1810 onwards) and loss of fishpond aquaculture • Inequitable access • Expansion of destructive fishing practices (e.g. dynamite fishing from 1860s)	• Cultural, societal, and political upheaval discouraged traditional cultural practices, leading to the loss of valuable stakeholder knowledge and undermining stakeholder engagement and access • Lack of effective management • Customary marine tenure systems eroded with many indigenous fisheries claims to resources lost or stolen • Transition from feudal, common property land ownership system to simple fee ownership • Additional impacts from sugarcane and ranching economy	(1), (3)	• Extrinsic cultural, societal, and political upheaval can create new opportunities for (and barriers to) growth • Balance across BG criteria may be impossible, continued sustainable growth requires trade-offs (e.g. social) • Relevance of extrinsic drivers and events, challenges & synergistic impacts of parallel growth in other sectors • New technologies and access to larger markets can exceed the capacity of the system • Erosion of traditional social structures leads to breakdown in environmental stewardship • Growth may not be linear, and have negative feedbacks • Provision of equity may be supplemented by extrinsic fisheries
10c		1893–1930	• Emergence of novel markets (tourism)	• Major societal, cultural, and political upheaval • Extrinsic factors restrict fishing (e.g. President Roosevelt declares the NWHI a biological refuge to protect resources from foreign commercial harvest)	• Widespread overfishing, private fisheries suffer as well as reef ecosystems degraded	• Market demand prioritized over sustainability • Synergistic stressors from multiple drivers locally and globally (new global market drivers, introduction of exotic species, major construction on atolls	(1), (2)	• Importance of extrinsic drivers and events, which may have both positive and negative outcomes • Interaction of political and economic change • Importance of time scales: Development of novel industries, political and social change, can all have unanticipated outcomes • Importance of spatial scales: impact of global markets

								• Failure to understand and address the limits to industry growth may have consequences, including system collapse
10d	Coral reef social-ecological systems: North West Hawaiian Islands (NWHI)	1950s–1970s	• Expansion of fishery alongside growth in other sectors • Sustainable resource use, recovery of reef ecosystems maintained	• Societal and political events (e.g. Hawaiʻi becomes 50th US state) • 1st MHI MPAs established but were small and isolated	• General constriction in NWHI fisheries (1915 – 2009)	• Abolition of private fishery rights • Rapid growth of human populations, coastal development and tourism industry	(1), (2)	• Gains can be offset by other human impacts. • Growth and sustainability are not always mutually exclusive: strong management action that may restrict growth but allow for sustainability. • Interaction of political and social change
10e		1970s–2009	• NWHI ecosystem recovery (ecological guilds) • NWHI improvements in reef jacks and trevally commercial fisheries (that collapsed 70s-80s) • NWHI increases in sea turtle nesting abundances	• 1970s-2009 no take MPAs established, • 2000-2009 Major environmental protections put in place for reefs in the NWHI • Native Hawaiian cultural renaissance- principles & traditions of stewardship reinvigorated	• MHI reefs highly degraded & fisheries depleted; no recovery of ecological guilds; thought beyond degradation thresholds • Monk seal, pearl oyster and monk seal in NWHI have not recovered from overfishing • Lobster fishery boom and bust in NWHI	• Overfishing permitted due to lack of appropriate management • Invasive species proliferate and land-based pollution also ongoing problems (more so in MHI)	(2), (4)	• Increased access can lead to overexploitation • Systems are dynamic: Variability in commercial fisheries alongside traditional approaches – create conflict for balance and growth • Although ecosystems/stock may recover from short-term and/or small scale disturbance: ongoing exploitation may lead to ecosystem degradation lasting centuries and exceeding degradation thresholds
11	Baltic seals (grey and ringed), Baltic Sea: initially hunted (pre-1960s), later protected	1900s – onwards	*1300-1800AD:* Baltic was the most important exporter of seal oil *1900-1950:* Seale exploitation as 'bounty',~200,000 seals harvested. *1980s-2000s:*	• Competition from Cheaper products devalued seal oil • Bounty system for hunting seals (1900-1960s) • Strong regional regulatory changes in multiple areas, 1960s regulation began and by 1980 full hunting ban.	*Pre-1980s:* • 80% declines in seal populations by c. 1950 • Further declines (90%) by 1970s • Decline in environmental and ecological well-being, poor status of	• Increased incentives for hunting (1900-1960s) • Excessive release of toxic pollution resulting from intensified industrialization • Lack of sufficient measures for regulating recovered seal populations	(2), (4)	• Extrinsic factors can hinder or help blue growth • Success for one group of stakeholders (conservationists) may not translate as success for other stakeholders (fishers) and can cause conflict between users/management challenges.

			• Grey seal recovery helped improve biodiversity and enhanced wildlife conservation	• Release of most persistent organic pollutants banned/restricted in 2004 • HELCOM protection of breeding sites 2015	seals and the Baltic Sea in general *2010s:* • Seal-induced losses for fishing industry			• Pressures can act in synergy, creating additional challenges for sustainable management
12	Multispecies and mixed fishery, North Sea trawl fisheries for cod, haddock, whiting, plaice, sole amongst other species (by 8 European countries)	1960 to present day	*Prior to 2000*: • Equitable access, many small-scale fisheries • Jobs in related industries (e.g. processing) *2000 onwards:* • Stabilisation of stocks across the fish communities • Improvement in stock status and yields since 2010; some recovery of the cod stock. • Recovery of ecosystem (seal population, birds and some whales).	*Prior to 1980s* • National governance • Political desire for sustainable resource use *1980s* • Political integration at EU level and development of common fisheries policies • Catch limits. effort reduction and decommissioning • Technological advances, particularly improvements in gear selectivity and stock targeting	*1960s-2000s:* • Many stocks overfished, collapse or severe depletion *2000 onwards*: • Decreased employment, particularly in England, Holland, and Denmark. • Inequitable access • Blighted coastal communities • Cultural losses	• Increased fishing effort and technological advances led to overexploitation • Transnational regulations, e.g. catch limits and decommissioning, reduced fishing effort and jobs • Technological advances in fishing and processing/ marketing (less person-hours needed for equivalent effort), and failure to understand impacts of such advances. • Mismatch between policy at transnational (reductions in effort) and national level (policy for affected coastal communities). • Insufficient investment in strategies for mitigating social change.	(1), (4)	• Transnational oversight is needed for effective management of biological risk in complex multinational fisheries • Appropriate international governance is possible but it can take decades for its effectiveness to be demonstrated. • In cases like the North Sea, where employment patterns and culture reflected unsustainable practices, moving to sustainable growth create clear "losers", even if management improves and long-term yields increase • Economics and culture need to be considered alongside catch and biological risk • Long-term strategies are needed that support impacted communities and diversify industrial base • Importance of stakeholder engagement to underpin legitimacy of blue growth initiatives and direct appropriate social intervention by government.
13	Autumn spawning herring fishery, Gulf of Riga, Baltic Sea	1920s–1980s	*1920-1940s* • Autumn-spawning herring very important stock in the Baltic • Contribution to diverse fish stocks and species	• Continued demand • Use of traditional fishing approaches (gillnets) enabled equitable access and resulted in sustainable exploitation	*1950s-1980s:* • Sharp decline in landings of autumn-spawning herring caused by unsustainable harvest	• Lack of appropriate management (scale of harvest, juvenile catch, distinction between stock) • Lack of cross-jurisdictional management	(1), (2)	• Importance of appropriate management supported by knowledge of the ecosystem and fishery (especially intraspecific variations) • Uninformed political management can drive overexploitation

			supporting commercial fishing economies • Equitable access to the resource • Social and cultural importance within small communities	• Favourable environment (low pollution/ eutrophication)	• Loss of biological diversity and reduction of portfolio of resources for exploitation • Decline in social-economic equity			• Technological innovation is not always in line with sustainability • Management should account for population structure to avoid loss of sub-stocks. • New knowledge of causes of delayed recovery could identify management actions to promote recovery.
14	Lobster fisheries, West coast of Sweden	1870–ongoing	*Pre-1890s*: • Both landings and high-value export markets increased with no obvious negative impact upon fishery sustainability *Modern time:* • Shift towards sustainable fisheries	*Pre-1890s:* • Technological advancements in combination with regulations helped to reduce lobster mortality and keep populations stable while encouraging growth in the fishery • Fishing rights often assigned to local fishers, limited access	*Post-1951:* • Expanded access to the fishery led to growth in numbers of fishers • Decline in stock size, despite management measures	• Technological advancements (both concerning gears and fishing equipment) enabled continued exploitation of stock beyond biological limits of reproduction • Lack of restrictions in fishery access • Inadequate management • Lack of monitoring of recreational sector	(1), (2)	• Open access is not the same as equitable access, and does not produce the same outcomes. • Monitoring and regulation of all sectors are necessary for sustainability.
15	Commercial wild harvesting of seaweed in Norway	1960–ongoing	• Sustainable harvest • Predictable harvest based on scientific understanding and ongoing monitoring. • Little inter-sectoral conflict.	• Emergence of new markets increased demand for alginates • Strong government-led regulations coupled with stakeholder feedback, scientific knowledge (e.g. growth and life history), and adaptive management (harvesting plans). • Investment in scientific monitoring coupled with ability to generate reliable predictions of harvest. • Technological innovation: shift from traditional practice to mechanised harvest	• Potential loss of equitable access in terms of the loss of small scale fishers • Lack of ability to grow harvest further without losing sustainable nature of harvest	• Increased market demand • Desire for increased efficiency fuelled by technological innovations. • Small-scale traditional operators may have been driven out of the fishery (data lacking)	(1), (2), (3)	• Importance of top-down control supported by scientific knowledge and stakeholder input • Ongoing investment in monitoring improves sustainability outcomes. • Lack of inter-sectoral conflict facilitates growth • New markets (extrinsic driver) provide opportunities for blue growth • Innovation benefits from external stimuli

16	*Crassostrea virginica* oyster fisheries (Aquaculture/ wild harvest) Gulf of Mexico, North Atlantic coast, USA	1800s–ongoing	•Sustainable aquaculture production • Wild reef restoration and closed fishing areas since the 1990s • Wild reefs support other non-oyster fisheries by providing habitat	• Sustainability concerns • Privatisation of areas allowing management of resource by individuals • Recognition of additional benefits from ecosystem services supported by reefs encouraged restoration • Stakeholder engagement in recovering degraded habitat • Policies/government investment to protect/restore reef areas	• Sequential collapse of wild fishery	• Ineffective management of destructive practices • Extrinsic technological advancements encouraged overexploitation • Synergistic anthropogenic stressors (e.g. pollution)	(1), (2), (3)	• Value of stakeholder engagement (for restoration) • Value of training and investment to promote aquaculture • Need for a policy framework to promote aquaculture (exemplified by the recent change in legislation in Maryland to promote uptake of aquaculture) • Importance of understanding links between habitats/services • Innovation benefits from knowledge exchange (other Essential Fish Habitat, also habitat restoration in rest of world) • Potential role of private ownership in promoting stewardship of marine resources
17	Nori edible seaweed culture in Japan	1600–2000s	• Gradual innovation in technology: increased yields, expanded the area available for cultivation. • Equitable access to resource • Continues to be sustainably exploited but heavily mechanised.	• Technological innovation encouraged by the government • Increasing demand due to WWII • Traditional knowledge of wild crop lead to early advances • Scientific discovery of life history in the mid 1950s, development of methods to reduce competition & expand growing area • Growers unions from ~1945 increased profits to growers, & provided a supportive infrastructure • Anthropogenic nutrient inputs supported nori culture & facilitated the expansion of culture area	• Production plateaued in Japan (i.e. lack of growth) • Shift to overseas production. • Since the 2000s fewer growers & the potential for less local equity	• Demand decreasing in recent years • Commercialisation drove a shift away from small scale family farming • Mechanisation meant fewer jobs	(1), (3)	• Value of stakeholder ecological knowledge on the stock and its habitat • Extrinsic drivers may occur at different spatial scales, and today the globalisation of labour markets mean production may shift overseas (this may mean that equitability needs to also be assessed across different scales) • The limits to BG may be social • Political change can drive socio-economic change that can have major impacts on existing production • Opportunities for BG are not linear, they may result from combinations of factors and feedbacks may occur • BG occurs alongside activity in other sectors and the impacts may

								be positive e.g. pollution from land-based activity
18	Oyster aquaculture in Deep Bay, Hong Kong	1300s - ongoing	• Equitable access provided a traditional source of income in local Deep Bay communities for centuries (1300-1950s) • Relatively sustainable use over many centuries • New technology (rope suspensions cultivation) helped increase production to a peak in 1958	• Traditional cultivation methods supported sustainable exploitation for centuries • Rope suspension cultivation was introduced and quickly adopted by oyster farmers	• Dramatic decline in production following 1958 peak • Shift away from an established blue economy towards cultural heritage industry only • Limited local demand for product	• Natural disasters including typhoons destroying oyster habitat, disease outbreaks • 1960-70s: Anthropogenic impacts from coastal development (sedimentation, pollution) led to declines in production • While the oyster industry was suffering in 1970s, Hong Kong was transitioning into a financial-trading oriented megacity with many more highly paid employment opportunities • Deep Bay oyster fishing industry is formed of ageing farmers with limited appeal for younger generation to continue fishery	(2), (3)	• Traditional skills and knowledge have underpinned the development and maintenance of BG for centuries, but coastal development (and the associated environmental degradation) can undermine financial viability if there is not modernisation. Diverse extrinsic factors can converge to undermine and limit blue growth: the oyster aquaculture industry in Hong Kong was maintained for centuries, but has been adversely impacted by rapid, modern coastal urbanisation which seems to be incompatible with oyster farming; declines in production are also associated with natural disasters and disease outbreaks • Institutional support for BG can depend upon perceptions, i.e. industries viewed as 'cultural heritage' might not be viewed as being economically viable despite scientific evidence to the contrary.
19	Kamchatka Red King crab in the Barents and Norwegian seas	1960s-onwards	• Creation of new, high-value fishery resource, followed by its growth and expansion • Significant income for a range of coastal communities (Norway), including previously struggling economies (east of 26°E)	• Intentional introduction of Kamchatka Red King crab from its native range into Russian waters of the Murman coast (1960s) • Soviet desire to establish profitable fisheries in the western Barents Sea • Protection of spawning grounds for key	• Risks disrupting ecosystem structure and function by an active predatory invasive species • Risks of undermining key commercial fish spawning grounds in the Norwegian Sea	• Intentional introduction of non-native species for commercial benefits • Intention to improve fisheries sustainability by banning small-scale coastal crab fishery and thereby protecting spawning females and juveniles (Russia, 2000s)	(1), (4)	• Thus far, generally positive example of human-driven non-native species introduction to develop an economically valuable yet sustainable fishery • Recognizing the value of a new resource by human society (in this case following a biological introduction) requires time and effort, as well as collaboration among management sectors.

			• Separate management in Russia and Norway with mutual informing about catches • Sustainable utilisation of unused fisheries' products thrown out to the sea (fish guts, heads etc.); Russian crab fishery classified sustainable in 2018 by the Marine Stewardship Council • Unlimited fishing west of 26°E (Norway) to control ecosystem effect of invasive species	commercial fish in the Norwegian Sea	• Ban of fishing within the 12-mile zone extirpating small-scale coastal fishing (Russia, 2000s)			• Importance of research and monitoring for observing ecological impacts of human interventions for blue growth.
20	White shrimp farming in Colombia, South America	*1980s* onwards	*1980s-1993:* • Rapid growth of shrimp aquaculture industry to become the country's 3rd largest export product • Creation of jobs *1999-2006:* • Scientific research on controlling disease, genetics, health and nutrition of shrimp enables survival and growth of the industry. *2007 onwards* • Community-based management technology incorporating sustainable traditional practices.	*1980s-1993:* • High international demand for product • Economic incentives for blue growth from government and the private sector. • Advantages offered by Colombia's climate and coastal environment. • Availability of low-lying estuarine areas suitable for aquaculture (but not agriculture). *1994-2006:* • Desire to maintain shrimp industry led to government investment in aquaculture research. • Establishment of specialist laboratories	*1994-1996:* National exports and profit declined. *1999:* Disease outbreaks of Taura Virus Syndrome and White Spot Virus (WSV). *Late 1990s-2015:* • Excellent yields, but low international prices meant production was no longer economically viable. • *2005:* Outbreaks of WSV decimated Pacific coast production, industry collapses. Caribbean	*1994-1996:* • Global shrimp industry collapsed, international prices fell and Colombian peso exchange rate falls • Increasing market pressure and poor environmental risk assessment made exports susceptible to volatile international prices. *1999:* • Semi-intensive practices and lack of understanding with regards to environmental limits and disease. *2002-onwards:* • Competition from SE Asia results in global over-supply • Market demand decreased 4-6% and global shrimp prices fall	(1), (2)	• Importance of Government support by investment for R&D. • Engagement of local communities in the development of ecologically sustainable production practices. • Value of traditional knowledge. • Identifying viable models for a domestic market for sustainability of the shrimp industry. • Importance of adequate risk assessment of production activities. • Value of rural aquaculture as a feasible way to provide food and security for coastal communities. • Investment and monitoring by key stake holders and government to improve sustainability outcomes. • Can generate significant employment, especially in regions where political unrest continues and sources of work are limited.

			• Protection of jobs for local people in aquaculture and processing. • Income for vulnerable coastal communities.	that produced genetically improved shrimp larvae for stocking in the farms • Intentional introduction of competitive species from the Pacific to Caribbean coast boosted production Government and private companies desire industry revival • Government and industry desire revival • Government grants provided to drive innovation in culture techniques and disease resistance.Stakeholder knowledge leveraged to support industry *2007 onwards* • Local communities desire to revive the industry. • Government and local entities desire for community involvement in sustainable aquaculture practices.	coast production continues. *2013:* • Closure of >25 aquaculture companies on the Pacific and Caribbean coasts. • Larvae culture laboratories closed. • Loss of jobs. • Industry shrinks, and except for one export company all other production is for domestic consumption	• *2005:* Columbian government removes tax incentives • *2013:* Price of shrimp food rises (possibly due to rising oil price)		• Necessity of reflection on industry practice, and value of monitoring, using knowledge and experience gained over the past decades. • New knowledge and scientific support may enable world-class shrimp aquaculture innovation in Colombia.

Supplementary materials 2

Case study 1: Balancing profitable harvest, equitable access, and environmental responsibility in inshore fisheries – Galway Bay in the mid-nineteenth century

Until the mid-19th century, the villagers of Claddagh, a small fishing settlement near Galway in Ireland, retained almost complete control over fishing activity in Galway Bay. They did so by customary, rather than statutory, means. Contemporaries described the Claddagh as a "singular community...still governed by a 'king' elected annually, and a number of bye-laws of [its] own," and noted that the fishermen were, "a powerful body, acting in concert [who] have hitherto been able to enact laws, not only for their own observance, but which they compel all others to respect" (Hall and Hall, 1843: 457; *House of Commons Return: Galway Bay Fisheries*, 1840: 1). These customary 'laws' were clearly aimed at retaining economic control over the fisheries, but they were also characterised by a concern for the long-term preservation of commercially important fish stocks. By the early years of the 19th century, the Claddagh fishermen were particularly active in resisting the spread of beam trawling, which they viewed as indiscriminate, highly destructive, and potentially damaging to the future of all the fisheries in the Bay. Shortly before 1820, for example, they violently – and successfully – resisted the efforts of a number of local men to establish a trawling company in Galway, cutting the lines, nets and sails of the trawl fleet, and "ill-treating the crews" (Hardiman, 1820: 293-5).

In the following decades, however, the Claddagh fishermen found themselves under considerable pressure to 'modernise' their attitudes towards the fisheries. In 1836, a national parliamentary enquiry condemned their "foolish prejudices and opinions" towards beam trawling, and, soon, economic and political interests had turned decisively against the kind of traditional controls in local fisheries that they sought to impose (*First Report on Irish Fisheries*, 1836: 93). In 1843, an Act was passed which, in effect, repealed all protective legislation that lay on the statute book relating to Irish fisheries, and it also paved the way for the establishment of a new Commission that would oversee them. In its first annual report, the new Commission made it clear that it fully supported the withdrawal of all restrictions on the use of trawl gear. Trawling was, the Commissioners wrote, "[a] productive and profitable

[mode] of fishing, and consequently should meet with encouragement, on public grounds". Furthermore, they dismissed fishermen's arguments as being "founded on prejudices and vague theories, not by any means confirmed by the facts" (*First Annual Report, on Irish Fisheries*, 1843: 2).

Despite the strength of the Claddagh community, and their traditional role as guardians of the marine resources in Galway Bay, they were unable to resist the tide of modernisation and the combined pressure of local and national economic and political interests. By 1854, the Fishery Commission was pleased to report that "the prejudice which so long prevailed among the Galway fishermen...has altogether subsided," and that the Claddagh men themselves would all be using trawl gear if they were not "prevented by the want of means from...adopting that mode of fishing". Yet, by this point even the Fishery Commission itself had come to recognise that the longstanding concerns voiced by the opponents of nearshore beam trawling had genuine substance. Later in the same report it was stated that:

> Notwithstanding our desire to overcome undue prejudices, and to see any spirit of insubordination checked, we are firmly persuaded that those who assert that the constant and indiscriminate use of the trawl net is harmless are in great error,

and, it went on to conclude that "we have abundant proof that this method of fishing may be carried too far, and that several places [around the coast of Ireland] have been trawled out" (*Report of the Irish Fisheries Commission*, 1854: 5). In a final twist, the Claddagh fishermen once again rose up in protest at the use of beam trawls in Galway Bay in the 1850s not, as they once had, because they feared it would be damaging to the fisheries in the future, but because by then its widespread adoption (not least by many of their own number) had, according to their own experience, "destroyed the fisheries in the bay" (*Report of the Irish Fisheries Commission*, 1860: 10).

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Case study 2: Institutional shifts in recreational fisheries

Recreational fishing, defined as fishing for sport or pleasure rather than for profit or to meet basic nutritional needs (FAO 2012), has a long history (Walton 1653). While the ecological impacts of this sector are commonly assumed to be less than commercial fishing (McPhee 2002; McClenachan 2013), the quantity of fish removed by recreational fishers can be substantial, even exceeding that of the commercial sector in some coastal ecosystems (Coleman et al., 2004; Cooke and Cowx 2004). The management of recreational fishing in Queensland, Australia today reflects this assumption, as it is primarily controlled by in-possession and minimum/maximum size limits. While this restricts the ability of individuals to land large quantities of fish in any one trip, there are rarely limits on the numbers of individuals able to participate in a recreational fishery. Thus, there is no total upper catch limit. This leaves fishery resources vulnerable to further increases in the number of fishers.

In Queensland, recreational fishing trips started to be reported regularly in the popular media from the 1870s onwards. While the numbers of people participating in recreational fishing in Queensland have only been estimated for the last two decades, popular media reports and interviews with fishers indicated that the numbers of recreational fishers increased from the late 19th century and throughout the 20th century (e.g., Thurstan et al., 2017; Thurstan et al., 2016). Up until the late 20th century, these reports demonstrated that the goal of fishing was (usually) to catch as many fish as possible (Thurstan et al., 2017). Often, this would amount to capturing tens of fish per fisher – sometimes hundreds of fish in total – during a single trip. These fish would either be given away or sold to private sellers, or sometimes were wasted entirely. Even when fishing alone, fishers appeared to maintain the element of competition, communicating their highest catches to local newspapers. The advent of fishing clubs further fuelled the competition in certain recreational fishing circles, with regional, state and interstate competitions regularly advertised from the 1920s onwards. While size limits in Queensland were introduced as early as 1887, it appears that these were seldom policed and that recreational fishers routinely disregarded these regulations, with many undersized fish caught and killed (Thurstan et al., 2017; In prep).

It is clear from the historical data, that fishing to ‘catch-all-kill-all’ was widely accepted in recreational fishing circles. Today, however, the vast majority of recreational fishers would not choose to catch and kill such large quantities of fish. What has changed and how has this influenced recreational fishers’ behaviours?

In the mid-1990s, Queensland authorities introduced in-possession limits on key species for the first time, and increased and started to routinely enforce minimum size limits. Many fishers initially disliked the new regulations but have since accepted further restrictions on key species, while the majority support in-possession restrictions to some degree (Thurstan et al., 2016). During the 1990s, key actors in the media (e.g., Frawley, 2015) also started to encourage catch and release practises, as well as the concept of caring for the fish; this was further taken up by fishing representatives (e.g., owners of fish tackle stores and competition organisers who encouraged prizes for the largest fish and greatest diversity of fish caught, rather than total numbers or weight of fish), while conservation-minded attitudes also became increasingly prevalent in the recreational fishery and wider community as a result of environmental concerns (Whatmough et al., 2011; Young et al., 2014).

Together, these international, national and regional changes likely aided a shift in societal norms where it became increasingly frowned upon for recreational fishers to catch and kill large quantities of fish at once, both outside of and within recreational fishing circles. This perspective continues to be reinforced in fishing blogs/fishing media today, where charter operators emphasise the importance of keeping single individuals rather than dozens of fish, and provide advice on how to improve the mortality rates of catch and release fish. Many recreational fishing groups around the world are also involved in efforts to monitor the health of their target species, or lobby against environmental issues affecting the marine environment (Cooke et al., 2016).

Despite these shifting attitudes, fisheries that are predominately harvested by recreational fishers are not always sustainable (e.g., Campbell et al., 2009). While recreational fisheries are rarely the sole cause of depleted stocks, recreational fishers certainly have a role to play in ensuring future sustainability outcomes. Today, recreational fishing groups in Australia have substantial political power, and, in some situations have successfully lobbied for recreational-only fishing zones and access to no-take marine protected areas (e.g., Sydney Morning Herald 2010; The Conversation 2013).

Recent research shows that legislation alone, even when enforced, cannot alter individual behaviours, and that behaviour is influenced more by societal norms (e.g., Bergseth et al., 2017). Societal norms in Queensland recreational fisheries underwent a substantial transformation during the 1990s that resulted in (by and large) more sustainable behaviours compared to historically. Research in Queensland has shown that legal mechanisms (e.g., bag limits), can contribute to behavioural changes if they align with other institutional changes, or are heavily policed, but not in isolation (Bergseth et al., 2016). Ensuring success within a blue growth context will thus require incentives that create social conditions where recreational fishers account for the ecological impacts of their behaviour as a group. One way to do this is to make fishers aware of how their actions will ultimately impact themselves and others within their social group (Burgess et al., 2016). In order to work across ocean jurisdictions (as blue growth is required to do) this will need to engage regional, national and international recreational fishing organisations.

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Case study 3: Fisheries in the Venetian Lagoon (Northwestern Adriatic, Mediterranean Sea)

The Venetian Lagoon lies in the north-west Adriatic Sea and is the largest single lagoon of the Mediterranean Basin, with a surface area of ~550 km². The lagoon proved valuable as a means of defense from tribal invaders in the 6th century (Neil, 2002), and later facilitated the growth of Venice, one of the most prosperous cities in Europe by the late 13th century, and the Republic of Venice (the so-called “Repubblica Serenissima”). The Repubblica Serenissima existed for over a millennium, from the late 7th century until 1797. Since the initial establishment of ancient human settlements in the area, people have become accustomed to exploiting the resources of the lagoon (Zolezzi, 1946), and fishing, together with hunting, was the main source of food for local communities (Sansovino, 1663). A wide literature documents how the Repubblica Serenissima strictly regulated the use of lagoon resources (e.g. Brunelli et al., 1940; Neil, 2002) to ensure sustainable exploitation as well as maintaining its morphological features (Fortibuoni et al., 2014). For over 1,000 years, the Repubblica Serenissima sustainably managed the lagoon’s resources, thanks to the numerous policies and regulations that were promulgated to prevent the degradation of environmental quality and ecosystem services (Neil, 2002). The successful management of the lagoon has been attributed to the promotion of a holistic and integrated management approach that adopted a long-term perspective, and strict legislation that was enforced by the authorities, which promoted public interests over private ones. In this way, equilibrium was achieved between the economic freedom of citizens and the protection of collective resources (Fortibuoni et al., 2014).

During the dominion of the Repubblica Serenissima, the fishery was an active area of legislational development (Scarpa, 1996). The main objectives of the fisheries policy were to ban fishing gear and practices deemed harmful to the lagoonal ecosystem, to protect fish fry from over-exploitation, and to try and balance ecological sustainability with social equity (Sormani Moretti, 1880). Overall, the aim was to ensure a high productivity of fish over the longer-term by respecting species natural cycles. The regulations governed the type of fishing gear, the fishing seasons, number of fishermen, the commercial size of fish, their conservation and trade. The punishments for regulatory breaches were severe and included imprisonment and the impoundment of fishing boats and gear (Fortibuoni et al., 2014).

From the 11th century, fishermen were organized into corporations called “fraglie”. Similar institutions for fishermen were present with analogous jurisdictions in France and Spain, called “prud’homies” and “cofradias”, respectively. These corporations had exclusive control over some fishing grounds, where only fishermen affiliated with the corporation were allowed to fish. Corporations had the power to repress abuses of the regulations, to control and punish fishermen who did not adhere to the regulations, and denounced them to the Repubblica Serenissima (Levi-Morenos, 1919). The authorities consulted fishermen’s representatives, the fraglie, when implementing laws regarding fisheries management, in order to take advantage of their experience and traditional knowledge (Scarpa, 1996). Hence, these corporations were directly involved in resource ownership and formed a sort of early co-management scheme that ensured the effectiveness of the legislation (Levi-Morenos, 1919; Raicevich et al., 2017) and avoided the so-called “tragedy of the commons” (Hardin, 1968). Indeed, it was in the fishermen’s own interests to preserve lagoonal resources over the longer-term.

During the Serenissima dominion, market access and sales were also regulated. Direct sales to consumers and fishmongers were prohibited: instead sales were restricted to the fish markets or were made through an intermediary, the “persenevole”, who controlled the price, quality, quantity and size of the fish sold. At the point of sale, the authorities fixed a maximum price for the fish to guarantee equitable access to resources, since fish was the most important source of food for Venetian inhabitants.

In 1797, the fall of the Repubblica Serenissima was followed by the progressive deregulation of fishing activities because of the political instabilities in the area and widespread poverty (Fortibuoni et al., 2014). Formally, during the occupying French “Provisional Government of the Municipality of Venice” (1805–1814) and later during the first decades of the Austrian governance, many of the laws and regulations concerning the fishery were maintained. However, all corporations were abolished, including the fraglie, resulting in a shift from a restricted to an open access fishery. Moreover, it was no longer necessary to hold a fishing license and fishermen could sell directly to consumers. This deregulation aimed to allow the poorest to access the fishery resources, at least on a subsistence level. Therefore, the number of people who exploited the lagoon’s resources suddenly increased, and since non-professional fishermen were mainly interested in acquiring only short-term benefits, illegal and destructive fishing practices spread (Levi-Morenos, 1919). The most prominent management problem after the Serenissima fell was, indeed, the lack of control and monitoring, two basic requirements for ensuring socio-ecological sustainability (Ostrom, 2009). In a letter of 20 April 1864, the Municipal Congregation of Venice deplored the proliferation of abuses and recalled the need to enforce the previous Serenissima regulations to avoid impoverishing the lagoon’s aquatic resources.

In 1866, Venice was annexed to Italy and on the 1st of July 1880, the first fishery legislation for the Kingdom of Italy became effective. The new regulations for the Venetian Lagoon were more permissive than during and shortly after the fall of the Serenissima (e.g. limitations on the mesh size of fishing gear were abolished) since the first aim of these new regulations was, for economic reasons, to guarantee open access (Sormani Moretti, 1884). Poverty afflicted many people who used the fishery as their main source of subsistence. Consequently, it is unsurprising that at the beginning of the 20th century, many scientists lamented the decrease in yields due to the unsustainable use of lagoon resources.

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Case study 4: Southern Bluefin Tuna aquaculture, South Australia, Australia

Contemporary management of southern bluefin tuna (SBT) (*Thunnus maccoyii*, Scombridae) fishing and aquaculture represents an effective framework for ecologically sustainable development; one that balances important economic and social outcomes with environmental integrity. SBT makes an important contribution to the economic value of Australia's seafood production. Although commercial interest in SBT began with fishing, by pole and line as well as experimental purse seining, nearly 100% of production is now from aquaculture in the form of ranching, which expanded steadily from 1990 onward (Metian et al., 2014). Australian production is centered along the southern coastline with juvenile SBT caught in the Great Australian Bight, through purse seining, which is then towed to Port Lincoln, South Australia to be grown-out in sea-cages. In 2015-16 the production of SBT, which is farmed only in the state of South Australia, had a total economic output (direct and flow-on effects) valued at AUD$306.1 million (EconSearch, 2017). SBT is the second largest aquaculture sector in Australia (by value) after farmed salmon in Tasmania (Savage, 2015), and the largest aquaculture sector in South Australia, accounting for approximately 50% (in 2015-16) of the gross value of seafood production from the aquaculture industry (EconSearch, 2017).

As a result, SBT aquaculture is also socially valuable, generating important employment opportunities in small, regional communities in South Australia.

SBT production via aquaculture is managed through dedicated state-based aquaculture legislation (Aquaculture Act 2001) and statutory policies that establish specific zones (local areas) and maximum biomass allocations, as well as operational frameworks incorporating leasing of the sea floor, licensing of the aquaculture activity, environmental monitoring of the activity, and compliance. An important feature of this regulatory framework is the inclusion of ecologically sustainable development as a central statutory objective. Marine aquaculture can be subject to strong negative public opinion (Froelich et al., 2017). The inclusion of a statutory imperative establishes an administrative requirement to ensure minimal environmental impact, but it also builds social equity by providing transparency and legitimacy in management. An important dynamic of SBT aquaculture is the reliance of the industry on feed from the South Australian capture fishery for sardine (*Sardinops sagax*). Wild harvest of lower trophic level species to provide feed for aquaculture can lead to overfishing (Naylor et al., 2000). Consistent with the development of SBT aquaculture, the sardine fishery in South Australia has developed rapidly, from approximately 10 tonnes in 1991 to a peak of over 40,000 tonnes in 2005 with catch most recently between 30,000 to 34,000 tonnes (PIRSA Fishery Report 2015). The potential negative impact of aquaculture on sardines is controlled through the use of fisheries stock assessment and management arrangements, which ensure a sustainable balance between commercial and ecological values (Goldsworthy et al., 2013).

Production of southern bluefin tuna (SBT) has, however, had a challenging history of development, from a past position of socio-economic indifference in the early to mid-1900's, including a lack of interest and capacity to obtain and meet market demand, through to the rapid upscaling of wild catches and overexploitation. During the early 20th century, SBT had a far less favourable economic return and societies' perception of the value of this species in Australia and expectations for its use were markedly different compared with today. In his parliamentary report of 1938, the then South Australian Inspector of Fisheries commented; "*Tunny is quite edible when boiled or even fried, but when canned it is delectable, and is called by Americans the 'chicken of the sea'.*" (Moorhouse, 1938). The Inspector also commented, "*For many years it has been known that tunny have been present in our waters,* *though they have usually been called 'bonito' by the fishermen who, considering them rubbish, have invariably cast them overboard whenever captured*."

Though it was well known by European settlers that tuna were seasonally abundant along the southern Australian coastline, it was not until the 1950s that larger and more regular consignments of commercial catches began to pass through the South Australia's principal fish market (e.g. Moorhouse, 1950). From the mid-1900s, several factors have driven the development of SBT production. In the 1940s and 1950s, the Government led surveys of pelagic species along the southern Australian coastline. These surveys sought to increase knowledge of the distribution and abundance of tuna in southern Australian waters and established the feasibility of tuna fishing. The timing of these investigations/surveys coincided with the development of a number of fish canneries, and an initial focus on supplying tuna for fish canning prompted initial growth in production. During the 1960s through to the 1980s, the globalization of tuna production saw a rapid up-scaling of fishing, which outpaced management and the development of profitable markets overwhelmed a timely response to overfishing. During this period, vessels that could spend considerable periods at sea fishing in offshore areas and aircraft for spotting tuna became key. Though Government interest in establishing a tuna fishery was high, substantial personal and often high-risk investment by individuals ultimately propelled the SBT fishery and SBT aquaculture into big business. These individuals have established an iconic reputation amongst Australia's seafood industry.

Today, the SBT stock has been exploited for more than 50 years, with total catches peaking at 81,750 t in 1961, and stock biomass (approximately 9% of virgin biomass) remains far below pre-exploitation levels, although recent strong recruitment is a positive sign of recovery (CCSBT 2017). SBT fishing is now managed through a comprehensive, multi-jurisdictional approach. In 1994, an informal agreement between Australia, Japan and New Zealand was formalised, establishing agreed collective limits for catch and creating The Commission for the Conservation of Southern Bluefin Tuna (the Commission). The Commission is an international regional fisheries management organization responsible for global management of the SBT population, which is listed as 'critically endangered' on the IUCN Red List (assessed 2011; Collette et al., 2011). Fishing is managed under a national quota system with an annual Total Allowable Catch (TAC) established for each member country, based on allocations that will enable production alongside targets for biomass recovery and fish used as feed in aquaculture. In Australia, a licence holder who seeks to access SBT catch from Australia's TAC must hold statutory fishing rights with the Commonwealth Government (the jurisdiction responsible for overseeing Australia's SBT TAC). The implementation of management arrangements at this scale, and strong catch limits, highlighted to the South Australian industry that future growth in economic output would need to be centered on value, rather than quantity. Strong economic outputs were identified and built through the development of high value export markets for sushi and sashimi in Japan that this product, and a select number of other tuna species, can reach (Metian et al., 2014).

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Case study 5: The Blue revolution in the Adriatic Sea, Italy I: Aquaculture

The Adriatic Sea (NW Mediterranean) hosts two case studies that present interesting lessons on Blue Growth. Specifically, these examples link to the development and spread of technological innovation as a means to trigger an increase in production, and thus economic return and social welfare, within fishing and aquaculture. These processes lead to what we call here the two Adriatic Blue revolutions.

Along the northern Adriatic Sea coastline, for at least a thousand years, traditional aquaculture activities were carried out in the lagoons and deltas; such estuarine ecosystems characterize the northwestern most part of this basin, from Trieste to the Po river mouth. Aquaculture activities, carried out in fishponds called “Valli da pesca”, were managed with particular attention, especially under the Repubblica Serenissima (Fortibuoni et al., 2009), since they provided a relevant contribution to local fish production. Several species, including seabass (*Dicentrarchus labrax*) and gilt-head seabream (*Sparus aurata*), were farmed. The production was based on the natural recruitment of the juveniles of these species to estuarine areas. Over time, due to the depletion of wild fish stocks, this aquaculture production become increasingly dependent from fries actively fished elsewhere (even from Albania lagoons, Botter et al., 2006), whose availability was, de facto, limiting the productivity of such capture-based aquaculture.

It is within this general context that, in the late 1970s and early 1980s, renewed attention was given to this sector that was driven by the spread of new technological improvements in aquaculture stimulated by the development of research activities for the artificial reproduction of fish farmed species. For instance, in this period the Veneto Region (Italy) funded a research activity that applied new technologies to seabass and seabream reproduction. Such developments (that rapidly spread across other Mediterranean countries) triggered the increase in availability of juveniles, and thus aquaculture production, that increased by 62% for extensive fish rearing and 977% for intensive fish rearing from 1988 to 1994 (Paquotte et al., 1996) in the whole Mediterranean. Finfish farming started a continuous growth in the Mediterranean till the early 2000s, reaching a peak in production of about 120,000 tonnes for the two species in 2005 (Theodorou, 2002; Theodorou et al., 2015). However, signs of crises emerged, in particular in northern Adriatic Sea aquaculture farms compared to other areas in the South-Eastern Mediterranean. Such crisis, was driven by the decreasing trend in the price of fish from countries like Greece (Paquotte et al., 1996; Theodorou et al., 2015). In addition the sector reached its “technological maturity”. Northern Adriatic aquaculture, mainly relying on semi-intensive and extensive rearing, in environmental conditions that are sub optimal (low growth in winter), with higher labour costs, could not sustain the competition with cheap fish from Greece and other Mediterranean countries. The rise and fall of aquaculture activities in this area, determined the loss of production, and employment, and many fishing ponds ceased farming and become (due to their high natural value) leisure sites for hunters.

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Case study 6: The Blue revolution in the Adriatic Sea, Italy II: Trawl fisheries

From the 15th century until World War I, the northern Adriatic Sea fisheries were dominated by the fishing fleet of Chioggia, a port located on the southern border of the Venice lagoon. Chioggia fishermen migrated back and forth from the western to the eastern Adriatic coasts to exploit migratory fish species (Botter et al., 2006; Fortibuoni et al., 2009). Fishing, including trawling, was carried out from sailing vessels until World War I. Stemming from the successful spread of steam engines in the North Sea fisheries (Thurstan et al., 2010; Holt and Raicevich, 2017), in 1912 the Italian government carried out the first “governmental fishing experiment with a steam trawler in the Adriatic Sea” (Paolucci, 1913). The aim was to increase catches (and thus economic returns and employment) from what was considered an underexploited sea, thus stimulating the growth of the whole fishery sector. However, for several technical and practical reasons, the experiment failed to show the potential demonstrated by fishing from steam trawlers in other areas. A few years afterwards, Levi Morenos, a Venetian economist who dedicated his life in support of Adriatic fishermen and their welfare, warned that any attempt to extend mechanical fisheries would firstly produce the emergence of competition between sailing and mechanized fleets, followed by the prevalence of the latter, and cause a subsequent employment crisis within low technology fisheries (Levi Morenos, 1916). These changes would be followed by a short-term increase in catches, generated by the increased (and more efficient) exploitation of coastal areas. Thirdly, declines in coastal fishery catches would trigger the exploitation of grounds further offshore. Once the capability for attaining increased catches came in line with the increases in fishing capacity, depletions in fisheries productivity would become apparent. Accordingly, Levi Morenos (1916) suggested that the Italian government protect fishermen’s employment by protecting small-scale coastal fisheries from industrial exploitation, as well as establishing no take areas on the high seas. Ironically, these measures are currently (more than a century later) advocated in Mediterranean fisheries and elsewhere (see, for instance, Raicevich et al., 2017).

The predictions of Levi Morenos (1916) eventually came true, but took several decades to be realised due to the influence of World War I and II, that interrupted the growth in the sector. Indeed, the governmental support for the use of engines in Adriatic (and Italian) fisheries was low immediately after World War I, when policies were more focused on establishing fishermen's corporations to allow easier management as well as have a building block for enforcing a welfare system. Moreover, the small capacity of the fishing industry during this period, typically characterized by family firms, did not facilitate individual investment in technology (Levi Morenos, 1916). It was only from the mid-1920s that the Italian government provided financial support for the adoption of engines. Despite this support, by the end of the 1930s, only 10% of Italian Adriatic trawlers had engines, and this technology was primarily adopted as an auxiliary tool for steaming from port to the fishing grounds, rather than for towing nets (D'Ancona, 1949).

After World War II, and in particular between the 1950s and early 1960s, engines and associated technologies (e.g. winches) were more broadly adopted. Adoption was stimulated by evidence of technology-induced increases in catches, and revenues, and new market opportunities, which demonstrated to fishers the opportunities brought about by investment in technology. This triggered a 'Blue Revolution' in the Adriatic Sea (Mozzi, 1967; Fortibuoni et al., 2010). This period, until the 1980s, was characterized by economic support of fishing activities by successive Italian governments, with the aim of increasing employment and production, as well as by almost unlimited access to fishing, which generated a large overcapacity in the Italian Adriatic fishing fleets. This lead to social and economic benefits, associated with increased fishery landings (e.g. at Chioggia Fish market from the 1940s to mid 1980s landings increased from 1,500 t to ca. 15,000 t), until the 1980s, when evidence for the local depletion of marine resources became apparent (Fortibuoni et al., 2017). The Adriatic Trawling Blue Revolution ended during this period, by which point almost all of the major technological changes up to the present day had been introduced (including new fishing gears), and signs of overexploitation (and overcapacity) were not addressed. From the 1990s onwards, the EU policies (and their national implementation) started limiting fishing capacity and effort in the Adriatic and Mediterranean seas (Raicevich et al., 2017). Despite the investments made in the sector, the application of monitoring, control and surveillance, and the reduction in nominal fishing capacity and effort, the Adriatic Italian fisheries are still in crisis (Cardinale and Scarcella, 2017): long-term sustainable growth (in ecological, economic and social terms) was not achieved, as Levi Morenos predicted.

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Case study 7: *Dugong dugon* fisheries of Southern Queensland

The first commercial *Dugon dugong* fisheries began in Moreton Bay in 1847 and in Tin Can Bay in 1850, Hervey Bay and Wide Bay in 1860, followed by fisheries in Rodds Bay, Repulse Bay, Wide Bay and at Cardwell, Cape Bedford and the Torres Strait Islands in the early twentieth century. Prior to this, indigenous tribes are thought to have hunted dugong in Queensland for millennia (for ~3000 years before present in southern Queensland (Ulm 2006), but for longer elsewhere (Minnegal 1982)), for whom the mammals held a deep spiritual and cultural value as well as being a source of nutrition. Dugong were fished for their meat and ivory, but the focus of their commercial exploitation was for their oil (a 100–150 kg dugong yielded on average 18 l) which fetched high prices overseas (Thorne 1867). This was one of the first commercial fisheries in Queensland and it went through several periods of success (high landings) and cessation followed by revival (Fig. 1a) until operations ceased in 1969 when dugongs became protected by state and commonwealth law. Thus, the commercial fishery operated on and off over a period of ~120 years and, overall, the catches in Moreton Bay were smaller than those further north near Hervey Bay and Cape Bedford (Fig. 1b). Today permits are issued for limited indigenous subsistence fishing, but many indigenous groups have consented to a voluntary ban on hunting.

The first European dugong fishery began at Amity Point, North Stradbroke Island in the 1830s. The approach to hunting was developed from the methods used by indigenous tribes, and this knowledge transfer was critical for establishing the early fisheries and their later successes – being both intelligent and shy with excellent hearing dugong hunting requires great skill. Indigenous peoples taught the Europeans to locate dugong from their blows, feeding traces (e.g. fragments of sea grass or oily substances) and tracks (furrows through the seagrass beds). They also shared their knowledge on dugong behaviour, the locations of fishing grounds and effective fishing techniques (Roughly, 1936; Thorne 1876; Welsby 1967; Lergessner 2007). The local Quandamooka tribe traditionally caught dugong using set nets placed in the mouths of small rivers or channels; other tribes speared or harpooned dugong from canoes or platforms (Bennett 1860). These techniques required a high level of skill that the Europeans did not possess, and therefore most early European fisheries were underpinned by indigenous labour (Lergessner 2007). There were also a number of independent commercial indigenous fisheries.

Dugong were an important component of the early pioneers' diet in the late 1820s, and in the 1830s small scale non-indigenous fishing occurred at Amity supplying the local market.

Violence over land seizures and access to indigenous fishing grounds near Redlands erupted in the 1830s (Lergessner 2007). European technology, e.g. more sophisticated boats and harpoon design, combined with traditional knowledge improved fishing efficiency. Between 1840 and 1847 a dugong hand netting cottage industry developed at Amity point. From this point onwards the first commercial fisheries were established and the most notable were those initiated by Fernando Gonzales at Amity and Dr Hobbs the Queensland government medical officer at St Helena. Dr Hobbs' facilitated the establishment of the dugong oil export industry by promoting its use as a medicine for lung complaints, such as consumption, claiming it superior to existing products such as cod liver oil. In 1854 dugong oil began being used in London hospitals and Dr Hobbs received orders for 1000s gallons that he did not manage to fulfil due to an inconsistent supply. The industry underwent multiple downturns and resurgences throughout its operation in Moreton Bay (Fig. 1a), which have been attributed to fluctuating demand from the overseas markets related to shortages of cod liver oil in Europe (during WW1 and WW2), the adulteration, or substitution, of dugong oil with shark oil by some producers (in 1858, 1859, 1869 and 1902), and inconsistent and unreliable dugong catches (Daley et al., 2008, Lergessner 2007). The Hobb's fishery at St Helena closed in 1859, but reopened in 1862 following renewed overseas demand, but this only lasted for seven years until again fisheries closed. Throughout the 1870s and 1880s fisheries were smaller although it was a period of peak exports (Fig. 1a). Low numbers of dugong, fishery closures, and other factors (e.g. flooding in 1908 meant seagrass beds were smothered as did oyster dredging, and increased shipping noise deterred dugong) saw less dugong fishing between 1880-1899 and 1910-1929. However, the 1930s were a very productive period in Moreton Bay and further north (Fig. 1b), perhaps stimulated by the great depression. Landings were high but sporadic and interruptions to the European cod liver oil supply during WW2 meant high demand for dugong oil. Although dugong oil was highly valuable (up to £14 l^{-1}) the unpredictability of the industry meant it never attracted significant investment.

Although access to fisheries resources may have been somewhat equitable initially, as Brisbane and the industry grew, commercial fisheries shifted from harpoons to nets and European fishers depended less on indigenous skills and labour. Combined with indigenous resettlement (1859-1879) conflict grew and social equity declined. Subsequently, the government attempted to develop indigenous fisheries by sponsoring their establishment at Bribie Island (1877-1879), and at the Hopevale mission at Cape Bedford (Fig. 1b).

The dugong fisheries were unregulated for much of their early operation although it was repeatedly claimed that the fishery was in decline (in the late 1850s, 1878-1879, 1884, in the early 1890s, 1908-1912, the late 1920s, 1940s and 1950s). In the late 1880s the Queensland Inspector of Fisheries spoke out about damaging fishing practices (including the use of harpoons, the catching of calves and breeding females) (Fison 1888). Subsequently, a government proclamation included dugong in the 1887 Queensland Fisheries Act, and attempts were made to manage the fishery by restricting fishing (in 1888-1890, 1893-1894 and 1905), limiting gear use (to 90cm mesh nets that excluded calves), and introducing licence fees for the boats and fishers. The fluctuating catches showed the dugongs susceptibility to over-exploitation is consistent with what is now known about their life history: dugongs live for ~50 years and do not start breeding until 6–17 years, they have a long gestation (12–14 months), and produce one calf at a time with >2 years between breeding (Marsh et al., 2011). Dugong are highly dependent on seagrass and habitat loss through sedimentation and noise pollution from shipping adversely impacted them. Furthermore, the herds are highly mobile and may move 100s km over a few days (Daley et al., 2008) complicating stock assessment and management.

The lack of sustained growth in the fishery seemed also to be strongly tied to fluctuating overseas demand. The overexploitation of dugong populations and their slow breeding rates meant the supply to these markets was often inconsistent. Adulteration of the oil was believed to have contributed to fluctuations in demand – inconsistent supply and high prices encouraged adulteration. Although dugong management began relatively early in the fishery it was unsuccessful at maintaining a sustainable resource due to the lack of a robust ecological basis for its implementation (no type or size restrictions, and no formal stock assessments). Estimates of the size of dugong populations include: >104,000 in Moreton Bay and 357,000 in Hervey Bay during the late 1800s (Jackson et al., 2001); 72,000 dugongs between Cairns and New South Wales in 1962 and 4220 in the mid 1990s (Marsh et al., 2005); and, 118–1019 from 1975 to 2011 in Moreton Bay, and 579–2547 from 1985 to 2011 in Hervey Bay based on aerial surveys (Meager et al., 2013). Although the initial population sizes seem to be overestimates (Marsh et al., 2005), they showed that in 2005 dugong populations were of comparable size to those in the 1990s and had not recovered to attain sizes even close to those estimated for the 19th or 20th century. Thus, although commercial exploitation has ended, pressures remain for dugong including anthropogenic environmental changes that threaten their food supply, as bycatch in gill nets and shark nets and from vessel collisions (Daley et al., 2008).

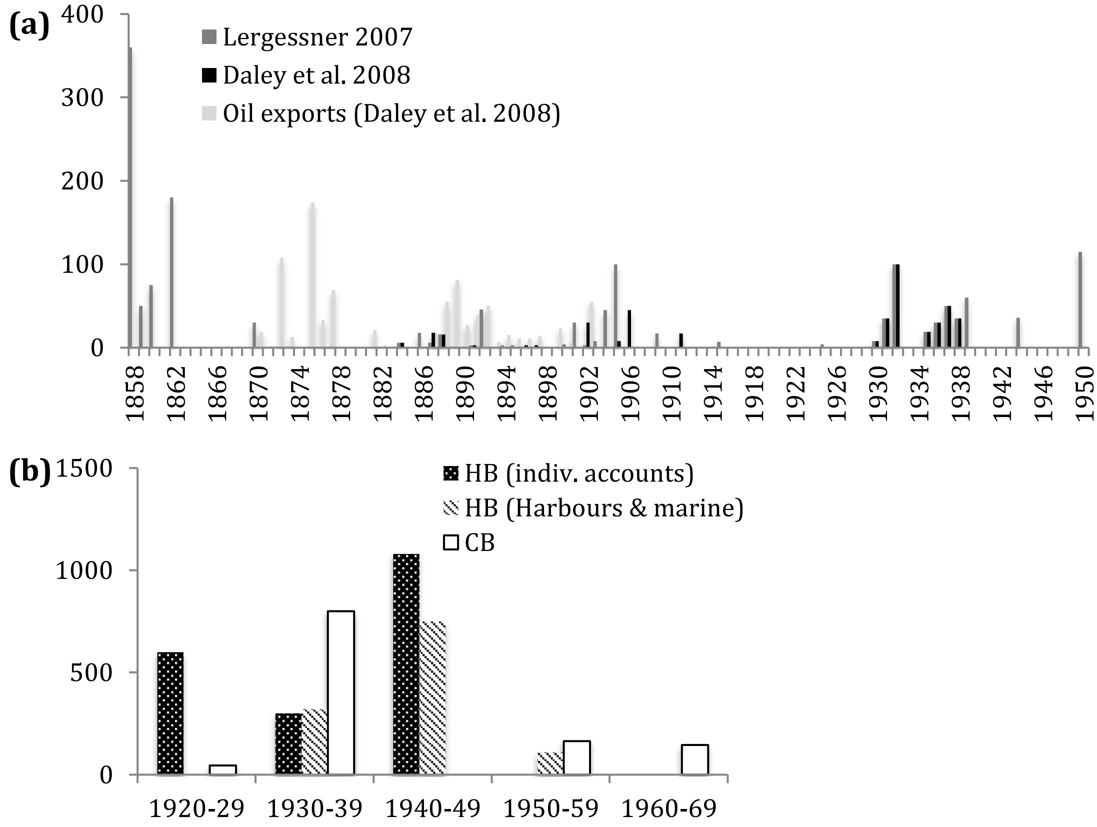

Fig. 1 (a) Number of dugong landed in Moreton Bay from 1858-1950. Based on individual accounts (Lergessner 2007), and landings data (Queensland votes and proceedings 1884-1900 and Queensland parliamentary papers 1901-1938; Daley et al., 2008). Also shown is the number of animals exported as dugong oil (Statistics of the Colony of Queensland 1870-1900 and Statistics of the State of Queensland 1901-1902; Daley et al., 2008) estimated assuming 4 gallons = 1 dugong. Not plotted: in 1847 ~360 dugong were caught. Note: in 1907-1908, 1910, 1912, 1913 no dugong landings reported (Lergessner 2007), in 1898, 1917, 1919 a 'few' dugong were landed (Lergessner 2007, Welsby 1867); there was a lack of data between 1912-1929 when Queensland fisheries reports stopped including dugong catches. Government enforced fisheries closures occurred in 1888-1890, 1893-1894, and 1905. Other years without either lacked data or catches were low. (b) Data from Hervey Bay (HB; individual accounts and Harbours and Marine Reports 1888-1965 (Lergessner 2007)) and Cape Bedford (Daley et al., 2008).

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Case Study 8: New England Fisheries of the Nineteenth Century

Fisheries in the United States today are managed to maximize the economic benefit to the nation (MSA 2007). While in practice, such a requirement has come to be defined as economic profit in the fisheries, this excludes consideration of the wider economic, social, political, and biological effects of any given removal rate. The experience of southern New England's nineteenth century inshore day boat fishery provides examples of how less economically profitable fishing operations provided more sustainable catch levels—and hence greater social and economic stability—than the more economically profitable fishery that replaced it.

Inshore fishing for "food fish"—often gadids, but also some flounders and other larger piscivores—had been part and parcel of the European colonization of New England. During the 18th and 19th centuries, a ubiquitous, but poorly documented day-boat fishery provided fresh fish for southern New England residents. This fishery worked waters close to markets and targeted whichever species was available to fishermen at the time. Indeed, as Timothy Dwight found in Newport, Rhode Island's fish markets in 1799, southern New Englanders included over 60 species (of the 112 represented at the market), as fit for the table. Requiring little capital to enter the fishery, and avoiding the processing overheads of the more lucrative offshore banks cod fishery, the ubiquitous inshore fishery likely fed and employed as many—if not more—than New England's vaunted and numerous schooner fleet.

According to testimony provided to a Rhode Island state commission investigating overfishing claims in the 1870s, the inshore fishery provided food for the increasing number of factory workers coming to southern New England in the 1830s onward. By the mid-1840s, the right to free and open access to coastal fisheries was written into the state constitution. By the 1850s, the fishery had become an integral part of the regional industrial economy, as it provided some means of insurance against the 'boom and bust' industrial cycles that often compelled owners to close factories and lay off workers until prices returned to profitable levels. According to one individual, when the factories closed, the newly unemployed workers went fishing off the beaches, and along docks and bridges, to acquire both food for their own tables and to bring in some small income. Thus, the abundant inshore stocks of food fish helped feed and protect families in the earliest and most tumultuous years of the United States' modern industrial economy.

Equally important to New England residents were stocks of forage fish—menhaden, mackerel, Atlantic herring and river herring—that food fish species chased inshore and within range of the inshore fishermen's hooks. Since humans had lived in southern New England, the more easily caught species—menhaden and river herring—were used for crop field fertilizer. In the early nineteenth century, as the offshore banks fishery adopted more bait intensive technologies from 1850, inshore day boat fishermen raised concerns about these species roles in attracting food fish inshore. To provide bait for the banks fleet, a newer, more capital-intensive form of inshore fishing, the pound net, began to harvest unprecedented quantities of forage fish. Despite being too expensive for most individual fishermen to purchase ($2000-3000 per net at the time; Baird 1871), locally owned pound net fisheries proliferated along Cape Cod shores after1850. Beginning in the 1830s, pound nets began to be used; by 1837 the first pound fishing company became incorporated. From 1839-1852 another three companies were established, by 1855 there were ten, and by 1871 45 pound net fisheries were operating in Cape Cod (Baird 1871, McKenzie 2010). As the pound fishery grew, it began to squeeze fishermen economically and through the adverse impacts on the inshore fisheries biologically. By the 1870s, pound nets dotted the entire southern New England coastline, catching not only unprecedented amounts of forage species for the bait market, but equally unprecedented volumes of food fish species that flooded the local markets. By the 1860s, inshore fishermen, alarmed at the declining stocks of food fish, mobilized politically to petition the state governments to ban pound nets, resulting in Massachusetts and Rhode Island commissions cited above. Their efforts, thwarted by banks fleet agents—including the chair of the Massachusetts commission, and numerous allied industry lobbyists—seeking to ensure a ready supply of bait, ultimately failed, and by the 1890s, the inshore fishers' families were forced to leave Cape Cod to take more steady, better paying, work in factories growing along the major transit conduits between Boston, Providence, and New York.

Healthy fish stocks provide more than just sustainable employment for dedicated fishermen. Abundant fish stocks allowed those most vulnerable to economic declines some independent means of subsistence until more permanent employment could be found. Additionally, while economically less profitable, de-centralized small-scale fishing operations spread the fishing effort and its ecological impacts across a greater geographic area and a wider variety of stocks. Finally, as fishing operations link people to marine resources and markets, they also link humans to those species that highly capitalized operations deemed to be simply industrial inputs (i.e. bait). As the case of Cape Cod fishing shows, however, blue growth in larger scale commercial fisheries comes at an ecological and economic cost to other fisheries and fishers.

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Case Study 9: Growth and stagnation of the Swedish fishing industry from 1910-1990

Swedish commercial fisheries in the early decades of the 20th century were technologically undeveloped and total fishing effort was low (Hentati-Sundberg 2017). After ca 1930, in line with other policies for industrial development, the government began to experiment with a variety of national subsidy programs to stimulate the growth of the fishing industry. The subsidies included grants for developing new tools and technologies, for building harbors and vessels, and to directly subsidize the price fishers were given for their catch to increase fishing effort. These subsidy programs were enhanced during and after WW2, primarily to ensure food on the table for the Swedish population, but also to increase national competitiveness.

Initially, the fishing industry expanded rapidly and led to increased catches and thus greater benefits to Swedish society. An increasing number of government programs were introduced and these further fueled the expansion – an expansion that likely would have occurred even without this heavy government involvement. Many policy programs were put into place, some of them were “smart” in one regard (i.e. price additions to stabilize fishermen’s incomes, where fishermen were provided with a fixed amount of subsidy for each kilogram of catch), but had adverse side effects such as wasting marketable fish and contributing to sustained/increased fishing effort that was only profitable because of government subsidisation.

From the 1960s onwards, the Swedish fleet had reached the stage where there were no new fishing opportunities to discover. The establishment of international fisheries legislation (quota regulations) led to declines in Swedish fishing opportunities in the formerly important North Sea fishing grounds (Hentati-Sundberg 2017). The new international quotas were based on the historic fishing catches that in Sweden had declined due to pursuing fishing opportunities elsewhere (i.e., the Baltic Sea).

During the periods of fishing crises, Swedish government policies generally failed to mitigate the problems created by a combination of technological advancement, industrial growth-promoting policies and a declining natural resource base. Instead, short-term economically-centered decision making led to an exacerbation of the long term ecological, social and economic problems (Swedish NAO 2008, Lövin 2007). It is only during the last 10-20 years that there have been signs of a shift towards more long-term sustainable fishing policies, which are putting greater emphasis on ecological sustainability (i.e. through the MSY goal) and strategies to reduce the fishing fleet. The European Union has had an important role in these developments. However, small-scale fisheries have continued to disappear and may constitute an example of where previous rapid growth has created problems for achieving long-term balance/equality of access.

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Case Study 10: Blue growth over millennial time scales from Hawaii

Kittinger et al., (2011) reconstructed long-term social-ecological relationships in Hawaiian coral reef systems during the past 700 years. This involved quantifying the effects of human stressors (overexploitation, invasive species, land-based pollution, disease and climate change) on different functional groups of reef-associated species. While a general trajectory of decline across functional groups was associated with human activities, there were discrete periods of ecosystem recovery, including a historical recovery of reef-associated biota throughout the Main Hawaiian Islands (MHI) (AD 1400–1820) and a more recent recovery in the Northwestern Hawaiian Islands (NWHI) (AD 1950–2009+). As expected, coral reef ecosystems recovered from human impacts when the intensity of anthropogenic stressors and the number of ecological guilds affected were reduced over long time periods (exceeding decades) and large spatial scales (entire island systems or regions). This limited the direct impacts of human stressors on reef systems and enabled recovery of multiple functional groups. However, reduction in these stressors was indirectly driven by a complex set of historical events, including consequent changes in social systems, which altered social-ecological relationships with the reef environments.

Achieving balance has to be evaluated within the context of a degraded ecosystem. Coral reef degradation has proceeded in the Hawaiian Islands in a similar fashion to reefs elsewhere in the tropics. However, in Hawaii the links between early traditional societies, reef ecosystems and sustainable exploitation of natural resources for food over the long-term were characterized by small-scale governance that actively sought to maintain marine resources while utilizing the services reefs could provide. As a result, periods of recovery followed ecosystem degradation. The main factors involved in the recovery of Hawaiian coral reef ecosystems and associated fisheries were related to local governance attempting to achieve balance between the natural provisioning of coral reefs with sustainable human uses of them. For example, starting in the 1400s, the rise of large chiefdoms resulted in the imposition of social controls over the consumption of some marine resources, particularly large carnivores and herbivores, with attendant conservation strategies that limited social access, even in the face of other human stressors such as large-scale fishpond aquaculture, agricultural complexes and animal husbandry.

Despite the early successes of local governance, traditional customary tenure was often overwhelmed by colonial economic interests, for example the development of whale fisheries that were associated with the arrival of Christian missionaries in the late 1700s. These were the first commercial fisheries established in Hawaii, and their initiation coincided with the discouragement of indigenous cultural practices by colonial rule, chiefly the re-direction of labour away from traditional fishing practices and the abolition of indigenous religious systems. In the face of these changes in governance, blue growth via commercial fisheries was achieved during a period of overall recovery of the Hawaiian coral reef ecosystems up to 1810, but further expansion resulted in an overall ecosystem decline after this date. Since then, there have been few signs of sustained ecosystem recovery in the MHI, although the NWHI have displayed improvements across various functional groups since the 1950s.

Some of the most important factors that either fuelled recovery or accelerated decline in Hawaiian marine reef ecosystems were stochastic and related to extrinsic factors – including human disease epidemics, WW2, and the attrition of able-bodied people away from local and towards foreign commercial enterprises. These events signal a large degree of uncertainty, both positive and negative, in social-ecological outcomes that cannot easily be predicted, but result in structural and demographic changes in human societies, and changes in the demands they place upon natural systems, and their quest for positive economic outcomes.

Later successes in both the Main Hawaiian Islands and the Northwest Hawaiian Islands were related to the development of marine protected areas (MPAs), since 1967 and 2010, respectively, and legislative success in regulating resource extraction. Balance in social-ecological systems was further enhanced through the reinvigoration of Native Hawaiian principles and the traditions of stewardship associated with a Native Hawaiian cultural renaissance, which has occurred since the 1970s. Growth and balance was and continues to be difficult to achieve in Hawaiian marine ecosystems because of the social-ecological dichotomies, such as the boom and bust fisheries alongside traditional approaches to customary marine tenure.

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Case Study 11: Baltic Seals

The Baltic Sea is inhabited by three species of seal: ringed seals (*Phoca hispida*, Phocidae) an Arctic species predominantly distributed in the northern Baltic, grey seals (*Halichoerus* *grypus*, Phocidae) which have almost pan-Baltic distribution, and harbor seals (*Phoca vitulina*, Phocidae), which only inhabit the southernmost Baltic Sea. Historically, hunting of seals has provided economic benefits, being at the same time a major anthropogenic stressor on all of the seal species in the Baltic Sea. Sealing has occurred since at least the Stone Age when the Baltic coastline was colonised by humans, and from 1300-1800 AD the Baltic produced the largest quantities of seal oil across Europe and was used to produce leather, soap and paint. The porigination of cheaper alternatives meant seal oil lost its value, Bounty-systems for killed seals were introduced by governments in several countries at the end of the 19th century (1889-1927 and 1941-1977 in Denmark, 1903-1967 in Sweden and 1909-1918 and 1924-1975 in Finland) to reduce competition between seals and fishermen for valuable fish stocks such as salmon. In some countries bounties lasted until the mid 20th century (MacKenzie et al., 2002). The original population size in the early 1900s was about 180,000 ringed seals and 80,000 Baltic grey seals (Harding and Härkönen 1999). The bounty-system induced significant hunting pressure on these populations and resulted in the extirpation of seals from several areas, the impacts were first recognised in the 1920s by specialist seal hunters. Seal population sizes declined by about 80% by the mid-20th century (Harding and Härkönen 1999). In the 1970s, Baltic seal populations declined further to about 3000 individuals in total (Harding and Härkönen 1999) due to organochlorine pollution, polychlorinated biphenyls in particular, which caused a reproductive disorder (Bergmann and Olsson 1985), that reduced seal fertility.

Seal hunting began being regulated (implemented through a quota system) at the end of the 1960s and a full hunting ban was endorsed in 1980, which was at least partly initiated and recommended by scientists (Genina 1980). During the same time-period (though, not associated with seal management), regulation/banning of the release of toxic pollutants into the aquatic environment also began (Frid and Caswell 2017) and most persistent organic pollutants were banned/restricted by 2004. These two independent measures, together with protection of the most important land seal breeding sites during critical time-periods (HELCOM 2015), have all contributed to seal population increases since the 2000s.

In addition to a Baltic Sea Action Plan that aims '...to reach and ensure favourable conservation status...' of seals and other threatened and/or declining species and habitats (HELCOM 2007), there are at least two EU Directives relevant to seals: 1) the EU Habitats Directive (European Commission 1992) with seals being listed in Annex II, whereby the member countries are obliged to monitor the status of seal populations; and, 2) the EU Marine Strategy Framework Directive (European Commission 2008), which explicitly requires species assessments using specific criteria for population abundance, distribution and productivity (EC Decision 477/2010). Baltic grey seals have now achieved Good Environmental Status (GES) both with regard to population abundance at ca. 30,000 individuals (Natural Resources Institute Finland 2016; GES level identified as 10,000 individuals) and the annual population growth rate (≥ 7%). However, ringed seals are still in a poor state at ca. 7,000 individuals (Natural Resources Institute Finland 2016) which is below GES levels (HELCOM 2015).

In contrast to the positive developments and benefits to the society from the conservation and biodiversity perspective, the recently increased abundance of grey seals poses major economic problems for coastal fishermen, both in terms of destroying fishing gears as well as the most valuable fish in the catch. This situation illustrates conflicting interests and trade-offs between different groups of stakeholders and users of the ecosystem, representing different views and interpretations of blue growth. This calls for flexible management systems that can adapt to new situations, e.g. when depleted populations recover and new regulation measures may be needed to optimise the benefits to all relevant sectors.

As a mitigation measure for the increasing interactions between seals and fishers (due to the increasing seal population), the seal hunt was recently reopened in northern Baltic countries (Estonia, Finland, Sweden) through national quotas. However, in most countries, the quota is not fulfilled for various reasons (e.g. lack of interest, limited or no market for seal products, loss of seal hunting ’memory’). This demonstrates that when an historical tradition for a resource has been lost, it may be difficult to resume even if the natural preconditions in terms of resource abundance reappear. This poses new challenges for finding a balance between different forms of benefits (e.g. conservation versus fisheries) and when attempting to optimize overall blue growth across related sectors.

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Case Study 12: Management of the North Sea Multispecies and Mixed Fishery

Commercial exploitation of North Sea fisheries dates back to before 1600 (Poulsen, 2008), and heavy exploitation of a number of commercial stocks has been occurring for over 100 years. The modern fishery can be characterised briefly as follows. Beam trawlers mainly target flatfish, particularly sole and plaice, but also take a bycatch of other species such as cod and whiting. Industrial trawlers use small mesh trawls to target forage fish such as sandeel and Norway pout for use as fishmeal and fish oil, but may also take a small bycatch of whitefish (cod, haddock and whiting). Otter trawlers use demersal trawls to target bottom dwelling fish including cod, haddock, plaice and saithe as well as the crustacean *Nephrops norvegicus*. Pelagic trawlers mainly target herring *Clupea harengus* and mackerel *Scomber scombrus* with small catches of other pelagic species.

Fishing technology evolved rapidly since the start of heavy exploitation (Engelhard, 2008), enabling an increasingly large harvest to be taken, but, together with increased fishing pressure, harvesting became unsustainable. Herring populations collapsed in the 1960s (Dickey-Collas et al., 2010), mackerel depletion occurred in the 1970s (Jansen, 2014) and cod *Gadus morhua* in the 1990s (Horwood, 2006). These successive stock collapses drove home the message that man's ability to harvest fish was outstripping nature's capacity to supply it, and that the North Sea fishery had to be regulated if it was to be sustainable in the longer term. This was made harder by the complex and transnational nature of the fisheries, but the advent of the European Economic Community (later EU) and the simplification of management by reducing the number of jurisdictions from many countries to just two (the EU and Norway), allowing development of a common approach to management (the Common Fisheries Policy (CFP)).

The underpinning philosophy of the CFP is managing to the maximum harvest that can be taken from a fishery in the long term without impairing the status or structure of the various stocks in the fishery (i.e. Maximum Sustainable Yield (MSY); Russell (1931), Mesnil (2012)). Over time, this resulted in various management actions to restrict the number and type of vessels operating, and the amount of catch they can take, as well as protecting areas that considered to be important from a conservation point of view, and making a special effort to encourage the recovery of cod, and hence avoid the collapse that occurred in Newfoundland, where the cod stock was a victim of the "bottomless sea mentality" (Bavington, 2011).

Using the ensemble model of Thorpe et al. (2015), Thorpe et al. (2016) investigated the outcomes of different fishing fleet combinations in terms of expected long-term catch yields and risk of stock collapse, and results (Figure 1) suggested that the state of the North Sea fishery was deteriorating through the 1970s as risks of fisheries collapse increased whilst yields declined, before stabilising in 1980s-1990s. From the early 2000s, the risks of collapse declined dramatically, without a significant loss of yield, suggestive of an improved management regime. Future projections suggest that if the current management framework continues to be implemented, there will be 10% improvement in long term sustainable yield, assuming no environmental changes.

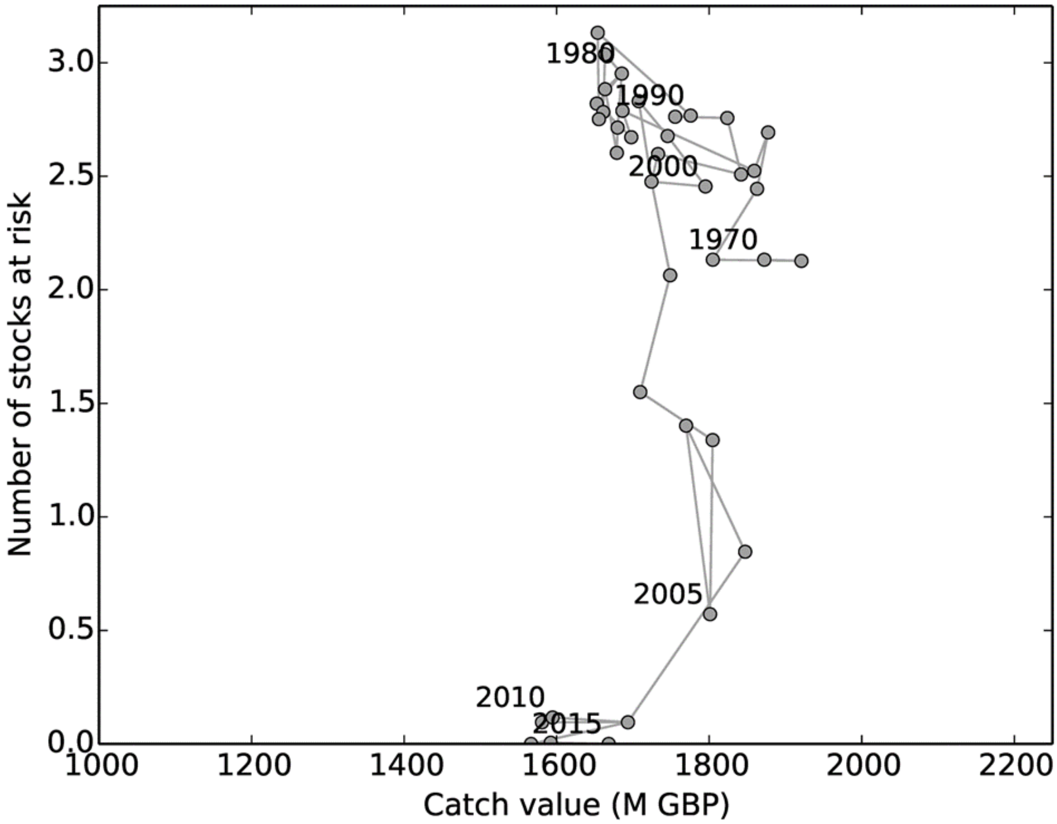

Figure 1: Simulated catch value and level of risk in the North Sea multispecies fishery for the period 1970–2015 (2015 figure based on estimated F - reproduced from Thorpe et al., 2016).

Comparison with the timeline of policy interventions suggests that setting total allowable catch limits (TACs) may have provided some stability from the 1980s, but it was the second round of vessel decommissioning which reduced the risks of stock depletion by removing excess fishing capacity. Meanwhile, yields have decreased, but only modestly, especially when compared with the reduction in risk. The main impacts were on jobs – decommissioning led to a much steeper decline in the number of boats and people employed compared to the decline in fishing effort. Consideration of overall outcomes before and after the implementation of transnational fisheries management (Table 2) showed that profitability, yield and stock status improved/ stabilised and risk was reduced. Thus, the political imperative to reduce overfishing has been successful, and a more profitable industry developed, but at the cost of fewer (albeit better paid) jobs, a less diversified industry, and social costs including a loss of traditional ways of life, blighted coastal communities and a weakening of the link between the general population and the sea.

Some of the trends towards the concentration of ownership in the sector, fewer larger boats, and towards increased automation of food processing, distribution and sales would have happened as a result of technological change, but this process has been accelerated by the application of management focussed on alleviating the risks of stock collapse (Table 1). Although it was necessary to improve fishing practices and make them more sustainable, there were heavy costs in terms of jobs and community cohesion. The number of people working in fisheries had reached a level that was not sustainable in the long term. Although improved management of the North Sea fishery set the scene for modest increases in yield and continuing progress towards better stock health, employment will not return to its former level. A possible role for government is to ensure that regional management focuses on fisheries and not fish stocks (Pope et al., 2006), and that increased profits from better management of existing fisheries and blue growth (alternative energy, eco-tourism, under-exploited stocks etc.) are used to offset the social costs of sustainable management change e.g. through investment in other industries that can support coastal communities.

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Case Study 13: Autumn spawning herring in the Baltic Sea

Autumn-spawning herring *Clupea harengus* historically made an important contribution to the Baltic Sea herring landings. For example, they contributed over 90% of herring landings from the central Baltic Sea in 1925–1927 (Hessle, 1931). Also, it was hypothesized that autumn herring was an important target fish in the Gulf of Riga (GoR) fishery in the late 17th century (Gaumiga *et al.*, 2007). However, this ecotype is now nearly extirpated, at least commercially, in the Baltic Sea (Fig. 1). As a result, its decline has reduced the biological diversity of living resources supporting local commercial fisheries (Schindler *et al.*, 2010). In contrast to the spring-spawning herring that can successfully reproduce in a relatively wide range of environmental conditions, depths and substrates, autumn-spawners have a more restricted range of environmental and habitat requirements for successful reproduction (Ojaveer, 1988). Changing environmental conditions due to e.g., eutrophication and climate variability/change may therefore have contributed to the current dominance of spring versus autumn spawners in the Gulf of Riga.

The most recent long-term (since 1920s) quantitative studies (MacKenzie and Ojaveer 2018) indicate that autumn herring landings in the northern GoR were often much higher in the 1920s–1930s than in the 1940s and first years of the 1950s (Fig. 1). Afterwards, landings increased exponentially and reached a peak by the end of the 1950s–early 1960s. Subsequently the landings declined steeply and continued to fall more slowly from the mid-1960s until the end of the 1980s. In more recent years, landings were up to two orders of magnitude lower than during the peak years (Fig. 1). The decrease in landings since the 1960s also led to a 6-fold reduction in the number of harbours where autumn herring were landed. Thus, the fish has lost its commercial importance. However, autumn herring has historically had very high social, cultural and economic meaning for small coastal villages, where it was caught in small-scale coastal fisheries by gillnets in the spawning grounds in autumn (Ojaveer 1988).

Exploitation rates (F=0.58) were unsustainably high during the mid-1950s – early 1970s, partially driven by the Soviet planned economy, whereby the set plan (determined by a centralized government) of fishery landings had to be achieved and a premium was paid if the plan was exceeded (MacKenzie and Ojaveer 2018), and the introduction of highly efficient technologies (i.e., pelagic pair trawling, Ojaveer 1988). This level of exploitation was ca. 2–4 times that now considered to be sustainable for herring stocks elsewhere in the Baltic Sea and in neighboring areas (e.g., North Sea). The exploitation included a high rate of juvenile removals, accounting for on average 40–50% of all the herring landed by number. Together these factors are considered to be major reasons for the rapid decline of stock biomass. The estimated annual SSB during the late 1950s to early 1970s ranged from ca. 8,000–27,000 t, which translates to a loss of approximately 4,000 –5,000 t yield for local sea-based economies in coastal regions of the GoR (MacKenzie and Ojaveer 2018).

Despite the recent strong overarching policy-legislative umbrella, i.e. the mandatory ecosystem-based management approach for capture fisheries (European Commission Common Fisheries Policy, MSFD), and genetic differentiation of autumn herring from spring herring in the Baltic Sea (Bekkevold *et al.*, 2016), autumn herring is not separately assessed and/or managed in the Baltic. The collapse of autumn herring in the 20th century took place under the conditions of either no, or during only the very early stages of, international management of Baltic Sea shared fishery resources. Thus, the collapse of the stock can be argued to be an 'unfortunate coincidence'. In addition, the lack of fish landed during the past several decades has not only resulted in the loss of knowledge of autumn herring spawning/fishing grounds and fishing equipment (boats, gears), but also the impoverishment of the associated social and cultural heritage in coastal communities.

Presently, the reasons why the stock has not recovered are unclear (e.g., bycatch in spring herring fisheries; eutrophication and climate effects on reproductive success). Nevertheless, there are many examples of commercial extinctions of other (and much larger) herring stocks in the North Atlantic, followed by recoveries after several years of low or no targeted exploitation. New studies are needed to address reasons why the recovery of autumn-spawning Gulf of Riga herring is delayed. Results of such studies could lead to proposals for management actions that could promote a recovery, and increase the portfolio of living resources on which local fishing communities depend.

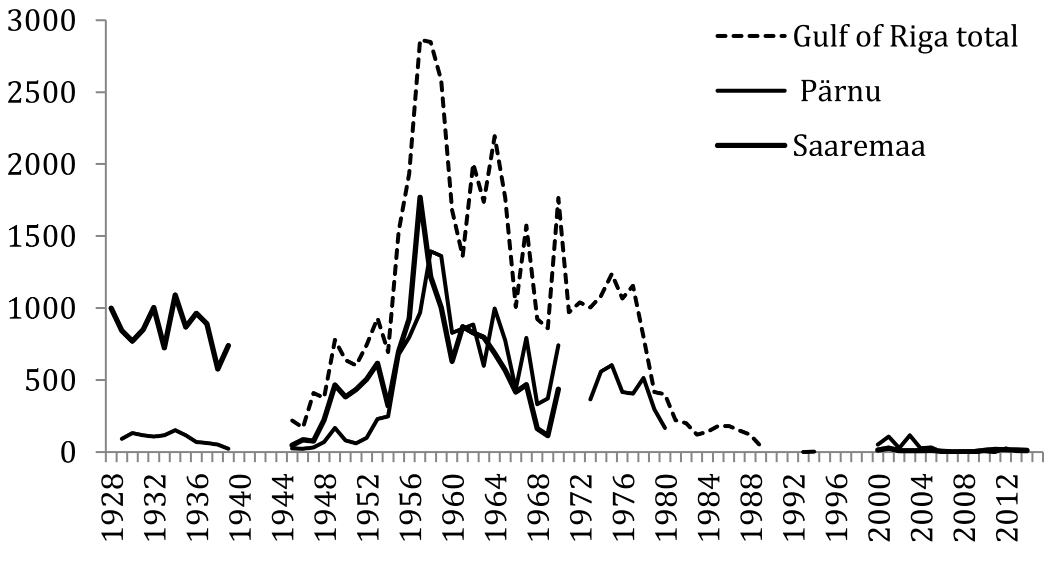

Fig. 1. Autumn herring landings (in tons) in coastal fishery in the Gulf of Riga: two sub-areas (Pärnu, Saaremaa) and the Gulf in total during 1928-2014.

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Case Study 14: 400 years of European lobster fishery in Sweden

European lobster (*Homarus Gammarus,* Nephropidae) has been fished for centuries throughout the north-eastern Atlantic, with export markets developing from the 17th century onwards (Hasslöf 1949). During this period, in the archipelago of the Swedish West coast, lobster was caught from the surface down to approximately 40 metres depth by both gillnets and pots. Typically, after harvest, Swedish fishermen would store lobsters live in pots at shallow depths. Although this practice preserved fresh lobsters for long periods, it sporadically caused large mortality events during the summer months due to high temperatures and possibly low oxygen levels. A substantial part of the catch along the Swedish west coast was delivered to the Royal family in Stockholm by horse and carriage (Hasslöf 1949), a long trip introducing further mortality. Despite this collective high mortality during the summer months, a summer fishing closure was not implemented in Sweden until 1830. At first this regulation covered only the northernmost part of the Swedish west coast, and from 1833 covered the Swedish west coast north of Göteborg. The seasonal closure was adjusted several times in the following decades with the intention to increase the survival and consequently the biomass of animals that could be harvested during the end of the year. However, no data is available to verify if such management measures were effective in allowing the stock to increase.

Particularly small sized lobsters were regarded as a delicacy. However, Dutch buyers demanded lobster individuals of a certain minimum size (approximately 20 cm total length (TL)) to pay top price as early as in the 16th century (Hasslöf 1949). In 1879 a regulation based on a minimum landing size (MLS) was implemented and set to 21 cm TL (von Yhlen 1880) to reduce the proportion of immature individuals in the catch.

By the end of the 19th century, close attention was paid by the public to the Swedish lobster fishery, which had developed into an important fishery with a gradual increase in the number of pots from 1875 to 1930, and with substantial revenues from national markets as well as from live exports, which were made in special vessels for the transport of lobster to the English, Dutch and at times also Danish markets. At the end of the 19th century around 1,800 Swedish fishermen were involved in the lobster fishery with approximately 28,000 pots worth a catch of around 300 tonnes per year. Local cooperatives of lobster fishing teams invested in sailing vessels with water filled cargo holds to transport live lobster to European markets. Although no economic reports have been retrieved, 30 teams from Northern Bohuslän invested in one vessel in 1886 and another two vessels in 1896, and maintained exports predominately to the Danish market until 1907 (Hasslöf 1949), and some form of the cooperative was active at least into the 1930s.

A major decline in landings and catch per unit effort (CPUE) in the 1960s-1970s coincided with the deregulation of the fishing rights for lobster in 1951. The number of pots per fisherman was regulated in 1937 to 40 plus an additional 35 for each extra person on the boat (Hasslöf 1949). Prior to 1951, fishing rights of many outstanding fishing grounds were assigned to local lighthouse tenders or pilots living in these isolated parts of the Swedish archipelago. In 1951 the regulation of assigned fishing rights was cancelled and the fishing for lobster in these areas was opened to the general public. The systematic collection of effort and catch data by the Swedish Rural Economy and Agricultural Society was ended in 1955 (Sundelöf et al., 2013) and the subsequent development of the fishery and stock is not well known.

By 1972, lobster population status was so weak that several management actions were introduced, such as an increase in MLS, followed by regulations including a moratorium on egg-bearing females, escape gaps for small individuals in the pots and further gear restrictions (e.g. net and fyke nets were banned) up to 2003. A study on the stock status using CPUE data from 1875-2010 describes the development of the lobster population along the Swedish west coast from a naturally regulated population to a fishery regulated one (Sundelöf et al., 2013). With the increased efficiency of fishing gears and the introduction of navigational tools and engines, the exploitation of the lobster stock intensified during the past century. Up to the 1930s, the dynamics of the lobster population still expressed periodic oscillations, indicating a naturally regulated population with a limited impact from fishing. On the contrary, in the following period stock fluctuations became instead influenced by fishing intensity and sea surface temperatures rather than density dependent factors (Sundelöf et al., 2013). By the end of the 20th century the harvest (both commercial and recreational fisheries) was around 100 tonnes and number of gears in the fishery between 60,000 and 90,000 pots per year; a third of the harvest compared to a century before, despite double to triple the fishing effort.

Restoration of local populations of lobsters in the Skagerrak, as well as increase in mean body size, has been rapid in no-take marine protected areas (Moland et al., 2013). Hence it seems that the lobster stock along the Swedish west coast, although severely depleted (Sundelöf et al., 2013), is not suffering from limited availability of larvae for recruitment. In 2017, new regulations (both for commercial and recreational fisherman) on lobster fishing were implemented based on simulation studies on individual lobster growth (Sundelöf et al., 2015). These included an increase in MLS (from 80mm CL to 90 mm carapace length), an extension of the seasonal closure and a decrease in the number of gears allowed per fisher in order to restrict the total catch of lobster with the aim to increase the survival throughout the summer and increase the overall productivity of the stock.

Today CPUE is low compared to 100 years ago and few commercial fishermen maintain a substantial part of their income from the lobster fishery. The lobster fishing fleet has also undergone several major structural shifts in this time. Up until the 1950s the fleet was dominated by "binäringsfiskare", i.e. stone cutters and local fishermen performing lobster fishing as a side activity to their main occupation. From 1875-1955, between 1,200 and 2,400 people participated to the fishery. In 1994, fishing regulations changed, separating lobster fishing into licensed commercial fishing and recreational fishing with a limited number of pots. The number of participating fishers is since then dominated by recreational fishermen. During the 2000s, a total of 5,000-9,000 people including both commercial and recreational fishers are estimated to take part in the lobster fishery each year.

In the most recent decade, the value from commercial harvest of lobster in Sweden has fluctuated around 9 million SEK (Anonymous 2018). Historically the value of the sales value of lobster, adjusted for CPI, has undergone large fluctuations being both larger and smaller compared to recent years. However, the value of the catch during the last decade only includes commercial official landings. Although no studies yet summarize the total expenditure by the lobster fishing fleet, it is estimated to be substantially higher than reported due to the large number of recreational fisherman engaged in the fishery for which the catches are not reported.

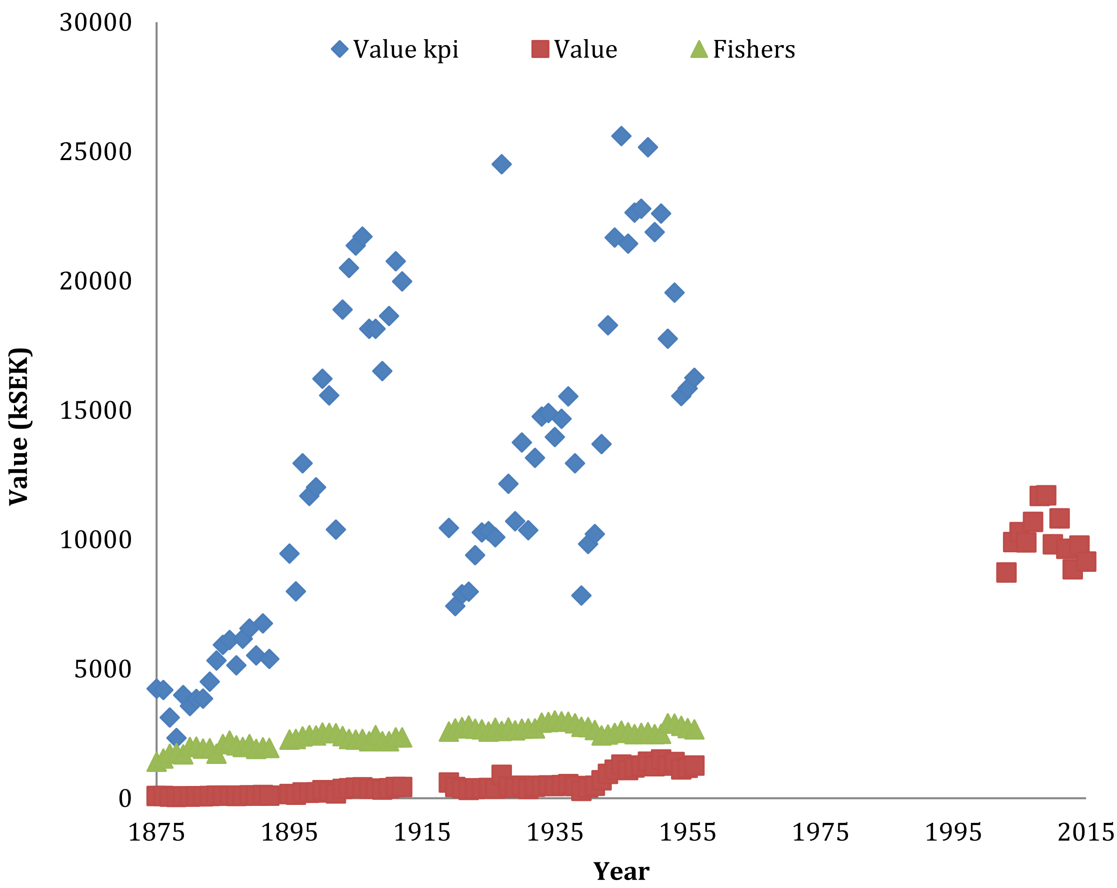

Figure 1. Development of actual value (thousands of SEK), value standardized to CPI (thousands of SEK) and number of fishermen from 1875 to 2015.

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Case Study 15: Wild seaweed harvest in Europe

Evidence for the harvesting of seaweed dates back over 15,000 years (Buschmann et al., 2017), and historically, seaweeds were harvested for a variety of purposes, including for food, animal feed, manure and a range of other domestic, medical and agricultural purposes. In recent decades, global demand has grown and expanded beyond these traditional uses (Buschmann et al., 2017). This includes the 20th century emergence of industrial applications such as in the hydrocolloid industry, which has fuelled global growth of seaweed harvesting, both wild and cultured (FAO 2016). Hydrocolloid products include alginates, carrageenans and agar, which are used widely as gelling agents and thickeners in foods, cosmetics and textiles, among other things (FAO 2016). While the majority of production still occurs in the Asian Pacific, in recent years growth in seaweed harvest and culture has also increasingly occurred in Europe and North America (Barbaroux 1990) where consumption of seaweed is now viewed as providing substantial health and nutritional benefits (Mouritsen 2016).

The expansion of seaweed consumption and industrial uses in Western cultures holds great potential for culture operations in these regions, which can operate with far fewer adverse environmental impacts compared to cultured marine fish such as salmon. The production of seaweed has also been proposed as a potential climate change mitigation tool, and enhanced seaweed production has the advantage of not placing extra stresses on the dwindling agricultural land or water resources (Duarte et al., 2017). While seaweed culture in Europe does not have as much of a historical precedent as the Asia Pacific, the harvesting of wild seaweed populations traditionally occurred in a variety of coastal locations across Europe. As demand for seaweed continues to grow, the overharvesting of seaweeds has been observed in some regions, but equally, some areas with a long history of subsistence harvests have successfully transitioned to commercial scale while maintaining the ecological sustainability of the fishery (Rebours et al., 2014; Rothman et al., 2006).

This case study focuses upon the mechanisation and commercialisation of wild kelp (*Laminaria hyperborea*) harvesting in Norway. Prior to the 1960s, wild kelp was harvested by hand-held poles, from small boats (sub-tidal locations) or gathered by hand (intertidal locations) along the west coast of Norway for use in the local agricultural industry as fertiliser (Vea and Ask 2011). During the early 1960s demand for kelp increased due to the development of a local alginate industry, the uses of which continue to grow today (e.g., MercoPress 2013). The large quantities of raw material required for processing meant that the traditional harvesting methods were inefficient and costly, while the physical labour needed for hand harvesting also meant the industry had trouble attracting workers (Vea and Ask 2011). The mechanised harvesting of kelp using modified trawl gear was consequently developed by the alginate industry in 1963 (Vea and Ask 2011). It is unclear how much kelp was harvested prior to mechanisation or how many people were involved in this cottage industry, but since mechanisation 17 new seaweed trawlers have been constructed country-wide and have replaced the smaller fishing boats used previously, and seaweed harvesting has expanded along the coast (Vea and Ask 2011). Today, harvests are variable but stable.

Since 1972, the locations where kelp is harvested along the coast have been divided into separate zones, managed by the Norwegian Ministry of Fisheries, which are harvested once every 4-5 years only to ensure regrowth of the kelp. This harvesting cycle is based upon investigations into the species' life history and has been adapted over the years in line with findings from continued monitoring of the stocks (Vea and Ask 2011). These surveys are also used to develop harvesting plans to improve the predictability of harvest volumes in forthcoming years. The Norwegian authorities regulate harvest to ensure that the available stock is fully utilised. Investigations into the wider social-ecological impacts of the industry have concluded that, although some impacts exist, overall these are minor and have not negatively affected other fisheries or restricted access to other marine users. As such, inter-sectoral conflicts are reported to be minimal (Vea and Ask 2011).

Given the relatively small quantity of wild harvested seaweeds produced globally (1.2 million tonnes) compared to cultured seaweeds (27.3 million tonnes; FAO 2016), it is clear that wild harvested seaweeds cannot meet the increasing global demands for seaweed produce alone, and that this demand will need to be met from aquaculture (Mac Monagail et al., 2017). However, at present, harvesting of wild stocks accounts for ~99% of the biomass of seaweed produced within Europe (Mac Monagail et al., 2017), hence the wild harvest is significant at the regional scale. The above example demonstrates that with careful management wild seaweed can be harvested sustainably and in quantities to meet industrial demand. While the potential for continued growth in this industry may not be as high as for aquaculture, the wild harvesting of seaweed also maintains much valued traditional skills and cultural links with the coast, as well as providing a source of equitable employment within rural communities. That there is interest in, and potential to expand the wild harvest seaweed industry is demonstrated by the recent granting of a license to a biotechnology company to experimentally mechanically harvest *Laminaria hyperborea* in Country Cork, Ireland (Mac Monagail et al., 2017).

Future challenges for the wild harvest industry include: Maintaining sustainable harvest strategies in the face of potentially increased/new sources of demand (or changes in coastal uses that may include enhanced local pollution), increased competition from aquaculture, and wider environmental changes that may impact seaweed abundance and distribution (e.g., warming sea temperature as a result of climate change); increased competition for intertidal marine space with other coastal operations (i.e., aquaculture, tourism, maritime activities); and maintaining recruitment within the workforce, which in many locations struggles to attract new recruits to the industry. Despite these challenges, this example demonstrates that where scientific understanding and monitoring is robust and continuously integrated into resource management, together with considerations of the wider ecosystem, a sustainable and equitable harvest industry can exist.

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Case Study 16: Oyster fisheries in the United States

Over the past two centuries, habitat building oyster species have suffered near universal declines globally (Beck et al., 2011). This is predominantly a result of over exploitation, although poor water quality, land use change and the spread of disease have also played a role (Mackenzie et al., 1997). Despite the collapse of much of the natural oyster reef area (zu Ermgassen et al., 2012), commercial harvest of the eastern oyster (*Crassostrea virginica*, Ostreidae) continues in the northern Gulf of Mexico and along the Atlantic coast of the United States (National Marine Fisheries Service Office of Science and Technology, 2016). The open access nature of these grounds and the extractive nature of fishing has, however, resulted in unsustainable harvests in many public areas (Soniat et al., 2012). Much of the wild harvest is therefore sustained through state supported “shell planting”, whereby state agencies replace oyster shells to mitigate the loss of the habitat as a result of the fishery (Schulte, 2017). Recent analysis in the Chesapeake region, however, indicates that this management is not cost effective. On the contrary, shell planting for the purpose of habitat restoration has been shown to give good economic returns through providing valuable ecosystem services (Grabowski et al., 2012).

From the 1990s onwards there has been a greater understanding of the wealth of ecosystem services that intact oyster reef systems provide to coastal communities (Coen et al., 1998, Coen et al., 2007, Grabowski et al., 2012). A growing body of evidence shows oysters may provide considerable improvements in water quality and enhanced denitrification (Smyth et al., 2015, Wall et al., 2011), they also provide coastal protection (Piazza et al., 2005) and enhance non-oyster fisheries due to their importance as nursery grounds (zu Ermgassen et al., 2016). These valuable ecosystem services, as well as their cultural value and recognition of the historical importance of oyster reef habitats in the region, have resulted in large scale restoration efforts explicitly for the purpose of recovering the reefs. Because the process of wild harvesting of oysters is destructive to the reef itself (Lenihan and Micheli, 2000), these restoration efforts are spatially discrete from areas of oyster reef managed for oyster fisheries. By managing the habitat independently of fisheries areas, a greater economic return on restoration investment is assured (Grabowski et al., 2012). This ecosystem service evidence base has been critical in garnering support for the inclusion of oyster reefs as Essential Fish Habitat under the Magnuson-Stevens Fishery Conservation and Management Act (2006), which in turn has resulted in increased investment in oyster restoration around the US (https://www.coastalreview.org/2016/07/federation-partner-oyster-reef-project/).

Alongside the increased effort in restoring oyster habitats, the demand for oysters for human consumption is increasingly being met by aquaculture, which now makes up the vast majority of U.S. landings. Many of the ecosystem services provided by oyster reef habitat may also be provided by oyster aquaculture, such as the provision of fish habitat (Erbland and Ozbay, 2008), and (under certain circumstances) enhanced denitrification (Kellogg et al., 2014). The switch from wild harvest to aquaculture is therefore increasingly viewed as a “win win” scenario.

Lessons learned from successful restoration in the Gulf of Mexico and from the Atlantic part of the eastern oyster's range have been important in knowledge transfer to other regions (Gillies et al., 2015). Oyster restoration in Europe and Australia began only recently and the transferred knowledge has been critical for fostering support for restoration projects. In the UK, oyster habitat restoration is undertaken not only for the expected biodiversity benefits, but also in the hope that restored sites will serve as brood-stock sanctuaries which should yield overspill of oysters to fisheries areas currently suffering from poor recruitment, in part due to oysters occurring at low densities with low reproductive output (smart solutions). In Australia, however, restoration is largely motivated by the evidence that protected oyster habitats provide important nursery habitats for fish and other invertebrate species, and hence may increase the productivity of these non-oyster fisheries (smart solutions) (Gillies et al., 2015).

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Case Study 17: *Porphyra* (Nori) culture in Japan

Seaweeds have been harvested wild for millennia in Asia, and there are written records of their medicinal use in China dating back to 3000 BC (Nash 2010). Seaweeds are an excellent source of nutrition (Periera 2012), and have long been recognised as a delicacy. Today, twenty-one species are consumed in Japan and at least six have been harvested wild since 700 AD. In 2015, ~1.85 million tonnes of nori was harvested worth US$1,000,000,000 (FAOSTAT 2015). In Asia production has focussed on *Porphyra tenera* and *Porphyra yezoensis* (collectively known as nori; Periera and Yarish 2008). *Porphyra* is the most valuable cultured seaweed in the world ($523 per tonne wet weight; Kim et al., 2017). Most *Porphyra* is cultivated in China, Japan and Korea.

Cultivation of wild *Porphyra* began in 960 AD in Fujian Province, China (Tseng 1981), with intertidal 'rock clearing' by people removing competitors from rocky outcrops immediately prior to spawning and thus enabling greater recruitment (Blouin et al., 2010). In Japan, wild collection has occurred since at least the late 16th century, and although the dates are disputed, commercial culture seems to have begun in Tokyo Bay from 1650 and in Hiroshima Bay ~30 years prior (Mumford and Miura 1988; Blouin et al., 2010). Culturing involved placing '*hibi*', bundles of twigs/branches, into nutrient rich estuaries in the autumn for the algal spores to naturally settle upon, and were then transplanted to shallow extensive intertidal bays for growing-on. Mature plants were harvested from the hibi from winter until spring. The tidal height at which the hibi were placed (Okasaki 1971) was carefully adjusted to ensure the *Porphyra* out-competed other naturally occurring seaweeds (and epiphytic growth was minimised). Once harvested the nori was dried, chopped and pressed between bamboo mats and left to dry in the sun. These practices slowly spread north and south (Arasaki and Arasaki 1983). Although *Porphyra* was successfully cultured for hundreds of years the crop remained unpredictable, the harvest period was short, and it depended on spore collection that could be limiting.

Technological developments in *Porphyra* culture methods achieved enormous increases in production and improved the reliability of the harvest (discussed further below). These included:

- 1868-1912 the replacement of traditional hibi with hemp rope (Nash 2010).
- 1900-1920 mats made from thin bamboo shoots were introduced for culturing the spores, which was followed by netting made from natural fibres such as hemp and palm (Mumford 1988).
- Up until the 1950s the origin of *Porphyra* spores remained unknown. The discovery of the alternate conchocelis life history stage (Drew 1949), previously thought to be a different species *Conchoelios rosea*, was a major development.
- 1960s nets made from synthetic fibres were introduced.
- Late 1960s farmers began attaching the nets to floating rafts.
- 1970-80s researchers searched for best-adapted strain of *Porphyra* (Mumford and Miura 1988), and more recently there was a change in culture species from *P. tenera* to *P. yezoensis* which is tolerant of higher salinities with spores that are easier to cultivate (Wildman 1974).

During the Meiji dynasty, from 1868-1912, the enlightened government promoted seaweed culturing and developments in technology were encouraged along all coasts that saw the replacement of the hibi with ropes, then bamboo mats and nets (Mumford and Miura 1988; Nash 2010). The more complex texture of the fibres improved spore attachment, and protected juveniles from desiccation by trapping moisture (Nash 2010). The mats or nets were subsequently staked into sediments using bamboo poles meaning the stock could be moved into deeper water and so required less intertidal area than the hibi.

Harvests of *Porphyra* increased slowly up until the start of WW2. The adoption of nets was slow due to the additional costs required (Mumford and Miura 1988). In 1945 after WW2 production doubled. Subsequently, discovery of the conchocelis life history stage meant spores could be grown on demand and in vitro (so nets could be seeded before transplantation into the sea). The result was a more reliable crop, an increase in the scale of practice and the possibility of culturing nori in areas where natural standing crops were low due to the lack of suitable substrate. Later advances in understanding of the factors provoking spore production meant it was possible to culture large quantities in vitro. By 1955 the conchocelis stage was becoming well used and production in Japan had increased four-fold from pre-war levels (Wildman 1974).

The adoption of floating nets also increased production because when nets were suspended horizontally, and plants were close to the surface of the water, it was found that adult plants could continue growing (albeit slower) when just above the water's surface. This reduced competition for space, and epiphytic overgrowth, from e.g. green algae and diatoms, and produced a tougher, darker higher quality product (Tseng 1981). Organic acids are also used to inhibit competitors by lowering local pH (Pereira and Yarish 2010). The use of floating nets meant the area available for culturing expanded up to 20 m water depth. In the 1970s production was six-fold higher than prior to WW2 (Wildman 1974).

The growth in *Porphyra* production was driven by both developing technologies, but also by increased market demand. During the war diets were supplemented with nori and it grew in popularity, and once WW2 had finished reserves were low because imports from Korea (that were high before the war) had ceased. After the war co-operative growers unions were established that provided greater incentives by improving grower's profits from 30% before and 60-70% after WW2 ended. The unions also had government sanctions to set and manage the nori grounds (Tseng 1981), and supported growers by providing drying equipment and supplies of conchocelis spores.

Eutrophication from agriculture and coastal population growth is also believed to have stimulated production to some degree. Together with the introduction of floating nets, the increasing anthropogenic nutrient availability allowed the area for culturing to expand away from estuary mouths. However, pollution also carries risks to public health due to the tendency for the algae to accumulate heavy metals (such as cadmium and mercury) produced by coastal industries.

Modern nori culture begins in spring with conchocelis grown in tanks, on substrates such as oyster shells until spores are produced. Nets are immersed in the culture until spores have adhered (1-5 days). The spores are grown by co-operatives, which sell to family farmers, who transplant their nets into the sea until the *Porphyra* reach 15-20 cm length (Tseng 1981). The crops are dried and sold to wholesalers. The family run businesses grow ~200 nets per year (Levine and Sahoo 2009), and nets seeded with juveniles/sporelings can be refrigerated to provide insurance in case of crop failure.

In the 1970s, Japan cultivated ~67,000 ha of *Porphyra* providing employment for ~27,000 growers. However, by 2008 mechanisation caused a decrease to just 4,868 growers with an 18% decline in yield (Levine and Sahoo 2009). General declines in the Japanese market have occurred since the mid 1990s, due to lower demand for high quality nori (Fig. 1). In 2015 Japan cultured 297,700 tonnes (Fig. 1), representing 75% of the total volume of Japanese aquaculture production, which was worth 80% of the total production (US $800,000,000, FAO yearbook 2017). Since the mid-1980s, Japanese companies have been developing the industry, using Japanese methodology to produce high quality product, in Korea and China where cultivation/production is cheaper (Levine and Sahoo 2009). By 2015 nori production in China was four times higher than Japan although its value was nine-fold lower, and in Korea production is comparable to Japan but its market value is half that of Japanese grown nori (FAOSTAT 2017).

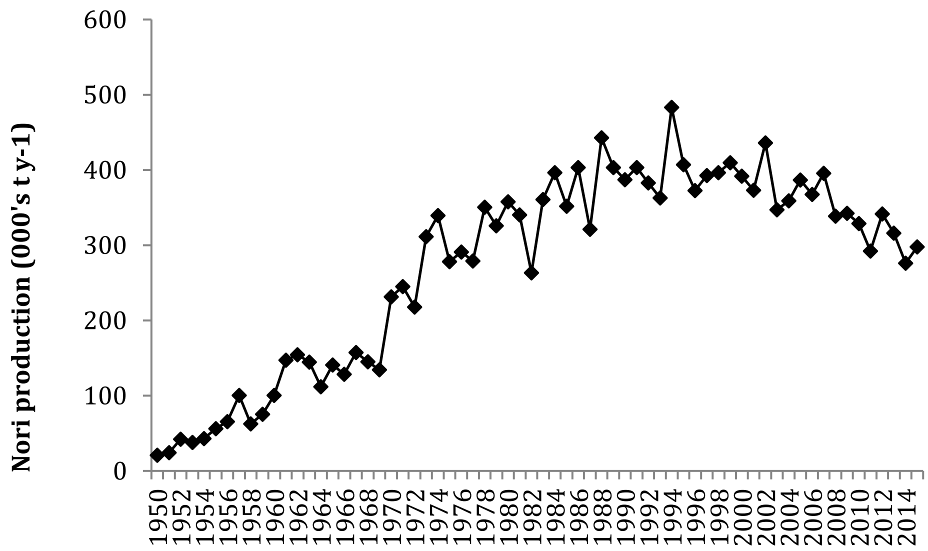

Figure 1. Nori production in Japan from 1950 to 2015. Data from FAOSTAT 2017.

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Case study 18: Oyster aquaculture in Deep Bay, Hong Kong development of a cultural heritage industry

Deep Bay in the Pearl River Delta, China, a semi-enclosed bay (~112 km^2) situated between north-western Hong Kong and south-western Shenzhen, has been a productive oyster (*Crassostrea hongkongensis*, Ostreidae) cultivation area since the 1300s (Lam & Morton, 2003; Morton & Wong, 1975). Up until the 1950s, oysters were cultivated via methods of bottom laying substrates (e.g., concrete blocks, stones and shells), and were either harvested intertidally by hand, or by long tongs or hand-picked by divers subtidally (Bowler, Yang, & Smith, 1984; Morton, 1975). This practice has largely been sustainable throughout this entire period and was the main source of income for generations of local families in Deep Bay (Bowler et al., 1984). More recently, however, the industry has struggled with low natural spat-fall, increased costs, declining production and the need to modernize.

While the approach of bottom laying has continued as an oyster harvesting method in Deep Bay, rope suspended cultivation was introduced by a local researcher in 1953 (The Kung Sheung Evening News, 1956). This method relied on hanging oyster clutches to ropes attached to floating rafts, enabling the suspension of oysters in the water column. This method was quickly adopted by oyster famers in Deep Bay, coinciding with a dramatic increase in annual production in the area from 1958 (Fig. 1). It should be noted, however, that while local sources identify the transition to raft culture (e.g. The Kung Sheung Evening News, 1956) some sources suggest oyster rafts were not widely adopted until the 1970s and 1980s (Bowler et al., 1984; Morton, 1975; Wong, 1975).

This period of blue growth, defined by sustainable use, equitable access, technological innovation and economic development, was short-lived. A natural disaster (an intense typhoon) destroyed the oyster industry in Deep Bay in 1960, with >2000 oyster famers affected and almost all oyster habitats being destroyed (The China Mail, 1960). During the 1960s–70s, further gradual declines in Deep Bay oyster production were noted and attributed to: 1) inefficiency of the bottom laying method; 2) increased sedimentation in the water column due to coastal development (i.e., dam construction); 3) signs of contamination in the oysters; and, 4) a shortage of younger farmers entering the industry as careers in finance and technology became more attractive (Morton, 1976). Subsequently, in 1975, coliform bacteria contamination (originating from local pollution) was reported in oysters from Deep Bay, leading to further reductions in oyster sales (Wah Kiu Yat Po, 1978) (Fig. 1). Finally, in 1979, oyster disease outbreaks (possibly protozoan parasite infestations) were reported in Deep Bay resulting in mass oyster mortality and production reached the lowest levels on record (Hong Kong Legislative Council, 1979).

While the Deep Bay oyster industry was simultaneously affected by natural disaster, pollution, and disease outbreak, Hong Kong was also transitioning into a financial-trading oriented megacity (Morton, 1976). Hong Kong Bay is heavily impacted by human activities being one of the busiest shipping ports in the world, with over twenty percent (~3700 hectares) of its natural coastline having been reclaimed and is ongoing as demand for further reclamation and coastal development increases (Morton, 2000; Ng et al., 2017). Although oyster aquaculture is no longer a main source of economic growth in Hong Kong, many other highly profitable industries having taken its place, limited oyster production continues in Deep Bay. In 2018, the Deep Bay industry produced 155 US tons of oysters (meat only), which was valued at 2.17 million USD (AFCD, 2019). Instead of being an established industry, oyster production in Deep Bay is recognised by the United Nations Educational, Scientific and Cultural Organisation (UNESCO) as “Intangible Cultural Heritage” (Intangible Cultural Heritage Office, 2019). Hong Kong people, particularly the oyster farmers, are proud of the native species (that shares its name with the city; *C. hongkonensis*) origins. While this may not translate in to greater demand for the product, anecdotal information suggests that it is pride in the local heritage that drives the local population to purchase oysters produced in Hong Kong and this may contribute to maintaining the current industry. Even though scientific evidence has demonstrated the social, economic and environmental benefits of oyster habitats and aquaculture globally (Grabowski et al., 2012), the existing Deep Bay oyster industry is mostly comprised of ageing farmers and has limited appeal for young talent (Cheung, 2013). The oyster aquaculture industry that experienced blue growth for centuries seems to be incompatible with rapid, modern urbanisation in the last 50 years.

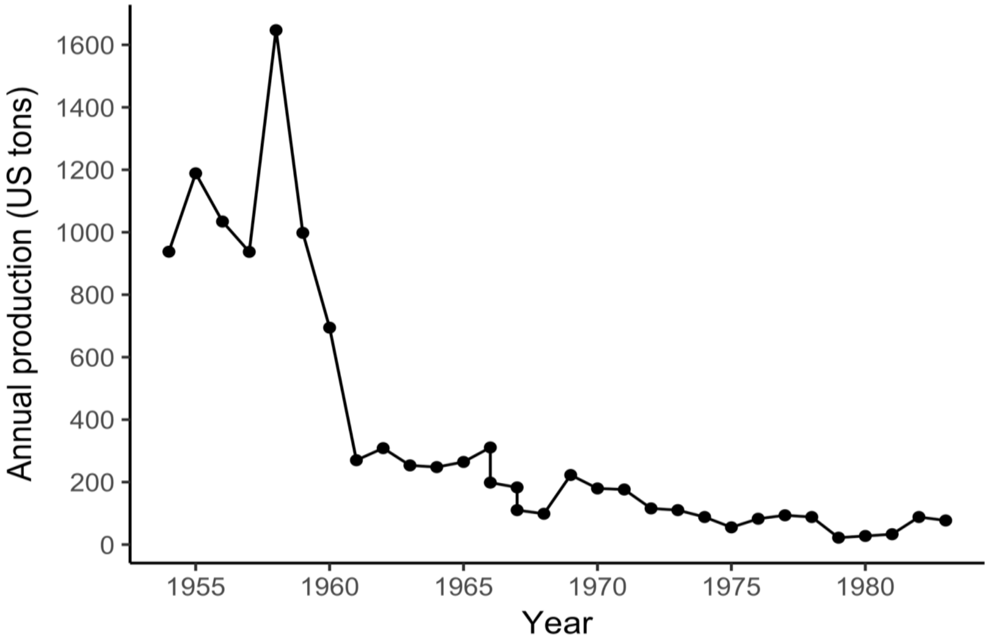

Fig. 1. Annual production of oyster aquaculture (wet weight) in Deep Bay, Hong Kong, between 1954 and 1983. Data were extracted from Morton (1975) and Bowler et al. (1984). Note that these production numbers do not include data from the Shenzhen, China side of Deep Bay (called Shenzhen Bay in China) because there are no available records of harvests. Anecdotal evidence does, however, suggest that the trend in annual harvest is similar to that seen in Hong Kong.

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Case study 19: The introduction of Kamchatka Red King crab in the Barents and Norwegian Seas

Biological invasions are considered among the most serious threats for sustainable use of marine resources. However, in some cases invasive species may become themselves an important resource, which might create a conflict between commercial benefits and ideals of sustainability. One bright example is introduction of Kamchatka Red King crab (*Paralithodes camtschaticus*) to the Barents Sea. Ironically, the current commercial success of this fishery is based on the Soviet practice, which began in the late 1920s-1930s, of introducing non-native species to a region with the goal of developing a productive fishery (Karpevich 1968). The commercial potential of the crab was recognized from experiences in its native range in the Russian Far East. Kamchatka crab was introduced into the west coast of the Barents Sea in order to create new fisheries closer to inhabited regions that might provide suitable markets for the product. Initial attempts to introduce the crabs in the 1930s failed, as rail transportation from the Far East was time consuming and the animals did not survive (Orlov, 1998; Levin, 2001). New attempts, in the 1960s, transported thousands of adults, juveniles and larvae by airplane, and repeatedly released them in to Kola Bay where they successfully established (Orlov and Ivanov, 1978; Orlov 1998).

Populations of the crab rapidly increased and they became widespread not only in the Soviet territory, but also by moving westwards across the border in to the warmer waters, of northern Norway. At first, the presence of Kamchatka crab threatened local fishers by disturbing their net fisheries. There was also concerns about the ecological ramifications, with the crab being a large vicarious predator with potential to disrupt the native Barents Sea benthic ecosystems. However, by the beginning of the 1990s, it became clear that Kamchatka crab had established reproductively viable populations, which could be harvested. Indeed, arrival of the crab across the border provided a rare boost to the economically struggling fishing communities of northeast Norway. This case shows the persistence of nature's agency to overflow state borders and governance not only altering the environment, but also the socio-political context (Höhler et al., 2019).

The historical development of these crab fisheries can be subdivided into three periods (Acoura, 2018). During a trial fishing period from 1994–2001, the crab stock was mostly distributed along the coast (within the 12-mile zone), and was managed by setting catch limits (agreed jointly by Norway and Russia), establishing a minimum commercial catch size and banning the harvest of females after fertilization in spring. During this trial period, Russia landed 9–300 tons per year and western Norway landed 40–350 tons per year. In the transitional period from 2002–2006, the stock range expanded outside of the 12-mile zone, and full scale commercial fishing began under joint Norwegian-Russian regulations allowing only traps. Limitations on fishing in Norway were set up east of 26°E, where crab managed to achieve maximum sustainable yield. West of 26°E, Norwegian fishing and extermination of the crab was encouraged due to the risk it represented to spawning grounds for key commercial fish species such as Atlanto-Scandian herring (*Clupea harengus,* Clupeidae) and Atlantic cod (*Gadus morhua*, Gadilidae). In Russia, fishing in the coastal waters was by small boats and offshore by specialized crabbers. The official landings comprised 900-12,600 tons annually, with unreported catches in both coastal and open waters approaching 25,500 tons (Acoura, 2018). Norway reported much lower landings of up to 2000 tons. Such high catches in Russia caused short-term declines in the stock.

Since 2007, the fishery entered a more stationary phase, the stock recovered and was characterised by good recruitment, especially in the eastern part of its range, and management is undertaken separately by Norway and Russia. The annual landings since 2007 ranged from 1150–6000 tons in Norway to 3700–9300 tons in Russia (Acoura, 2018). Russia allowed fishing only outside of the 12-mile zone, prohibiting catches of the nearshore of females and juveniles, and excluded small boats in favour of large crabbers, with permits issued to one large company only.

The most recent period demonstrates that even with introduced species, management varies according to the differing overall management approach of the country of concern (i.e., small scale inshore fisheries in Norway and large highly centralized fisheries in Russia). In Norway, crab introduction to a large extent improved the well-being of the local fishers whereas in Russia it only benefitted large commercial industries. Increased abundance of crab did not coincide with major ecological consequences, as originally feared, and research has shown that the crab is not very selective in terms of its prey. This could be the reason that it did not disrupt benthic community biomass, diversity or structure significantly (Britayev et al., 2010) compared with prior to the introduction of the crab, although some variation was likely caused by fishing rather than the crab (Tsyganova et al., 2015). Climate change might be another key environmental factor which may cause notable changes in benthic communities (Birchenough et al., 2015; IPCC, 2019). At the same time, it should be noted that, with increasing human pressures and environmental variability, especially in the Arctic, the Kamchatka crab could still have unanticipated impacts on Barents Sea marine ecosystems.

The severity of such risks is weighted by experts very differently. On the one hand, this fishery was certified as sustainable by the Marine Stewardship Council (Acoura, 2018). On the other hand, Kourantidou and Kaiser (2019) believe that it represents another example of “gilded trap” described by Steneck’s and coauthors (2011), when short-term benefits result in underestimation of eventual negative social and ecological consequences. In particular, they express doubts in the transparency of the Russian fishery management system. This system however, is basically the same as in other fisheries in Russia, and was proven to be effective enough in multiple Russian MSC certifications (Lajus et al., 2018).

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Case study 20: White shrimp farming in Colombia, South America

Marine shrimp farming originated in South East Asia, where for centuries shrimp were raised incidentally by farmers. By the late 1980s, shrimp farming was the highest value seafood entering world trade (USA, Japan and Western Europe), increasing from less than 1% of world seafood trade in 1980 to around 20% by 1988 (FAO 1990). Consequently, marine shrimp farming developed as an important export product for countries that were environmentally suitable and had low labour and operational costs, e.g. South Asia and South America (mainly Ecuador and Panama).

Latin American commercial exploitation of shrimp began in Ecuador in the 1950s, where shrimp farming initially emerged as a means of survival (Mock and Murphy1970). It subsequently became the world's leading shrimp farming industry, and an important source of work and foreign exchange for the country's economy. Today, the shrimp species, *Penaeus vannamei* and *P. stylirostris,* from the Pacific and Caribbean coasts of Central and South America, are grown all over the world.

Colombia, which borders Ecuador, was predominantly an agricultural economy prior to the 1980s. Since 1983 the country implemented a scheme of tax incentives for marine shrimp farming and export from the Caribbean coast (Miniagricultura 2005). Due to regional climatic and environmental conditions, Colombian shrimp farming became a year-round industry. Shrimp culture was promoted in the "National Plan of Exports, 1984-1990", by the Colombian Government under then-President Belisario Betancur, who, along with local capital investors and business groups from both the Atlantic and Pacific Colombian coasts, focused production almost exclusively on the export market. The Colombian Association of Aquaculture (ACUANAL), supported by the Ministry of Agriculture and Rural Development (MADR), COLCIENCIAS and the Colombian Aquaculture Research Center (CENIACUA), together generated the scientific and technological knowledge required to improve genetics, health, nutrition, management and sustainability of Columbia's shrimp industry (CENIACUA, 2017). By the late 1980s, the shrimp industry was Colombia's primary export, after coffee and bananas. Within a few years, this "new" aquaculture industry contributed greatly to job creation, use of low-lying estuarine areas (unsuitable for traditional agriculture due to the high salt content), and quickly increased foreign exchange income thereby giving a rapid return on investment. Production rose from 122 tons in 1983 to 6,622 tons per year in 1994 (US$ 600 thousand to US$ 30.2 million (Minagricultura, 2017)).

However, by the end of 1994 and on into 1996, exports of Colombian shrimp fell dramatically. The country's exchange rate and poor risk assessment of the impacts of disease made exports volatile and susceptible to uncontrollable international prices. Likewise, the appearance of Taura Virus Syndrome (TVS), and then the subsequent arrival of the White Spot Virus (WSV) in 1999, left the shrimp industry in a state of profound decline. Also, the economy of industry decline when international prices fell and the Colombian peso was devalued against the US dollar. However, CENIACUA successfully controlled these diseases, permitting the survival of the industry, which in 2006 achieved more than 20,000 tons of shrimp production from 4,000 hectares. Nevertheless, since then the recurrence of unfavorable economic situations and the successes of the past have yet to be replicated. (Minagricultura, 2016).

By the late 1990s extremely successful shrimp farming was developing on the Caribbean and Pacific coasts (Tumaco), mainly using the species (*L. vannamei* and *L. schmitti*), which are native to the eastern Pacific. These species demonstrated the best yields in terms of growth, food conversion, and survival. Similarly, cultivation and harvest of these species can be timed, in terms of size and quality, to take advantage of optimal market conditions. Several large companies invested in marine shrimp farming along the Caribbean coast and numerous farm-laboratories, dedicated to the maturation and production of larvae also arose (CENIACUA, 2017). These laboratories successfully overcame the TSV on both the Pacific and the Caribbean coasts. However, by 1999, the WSV impacted the Tumaco industry on the Pacific coast to the extent that farming there had totally disappeared by 2005. Fortunately, shrimp farming along the Caribbean coast was not impacted and went on to achieve 97% of total domestic production.

Due to the rapid increases in South East Asia production beginning in 2002, the world entered a period of oversupply (above 12% per year) and low demand (down by 4 to 6%). As a result of this supply and demand imbalance shrimp prices deteriorated over the next twelve years. Moreover, the Colombian government's tax incentives for shrimp exports were eliminated by the end of 2005. By 2013, increases in the cost of concentrated shrimp food (which were mainly imported and hence associated with higher oil prices) depressed the industry, causing more than twenty-five companies to cease farming and for larvae culture laboratories on the Caribbean coast closed (CENIACUA, 2017). At this time production was entirely destined for domestic market with the only export company for shrimp in Colombia being Océanos S.A., on the Caribbean coast (PTP, 2014)

Since 2007, Tumaco's shrimp farmers have been receiving grants, including technical and social assistance, from the government to develop entrepreneurial projects designed to introduce changes in crop management and sustainable aquaculture practices. These practices are based on knowledge gained by the communities through negative experience of the past particularly in areas of political unrest. If shrimp aquaculture is to survive and thrive, careful management of economic, social and environmental factors must be adopted. Approximately one thousand abandoned shrimp ponds have been restored to production under bio secure conditions by using a community-based management schemes that rely on traditional sustainable practices. These practices include stocking of larvae resistant to disease, the use of low stocking densities, microbiological treatment of pond bottoms and waters. This form of traditional management and the application of strict traceability of procedures in processing plants has ensure and improved cost/benefit to production.

There are positive signs (particularly from abroad) suggesting that possible turning points to the present industry crisis have been achieved for the short- and medium-term. Local entrepreneurs and representatives of the national government, i.e. the Ministries of Trade and of Industry and Tourism, have shown a desire to revive the shrimp industry. By rethinking the comparative advantages offered by Colombia’s climatic and environmental conditions along its coasts, and the knowledge and experience gained over three decades, there is indeed room for more growth in shrimp farming and for a successful export industry in Colombia.

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Supplementary materials 3

1. Recommendations that apply to the planning process

A. Define the temporal and spatial scales across which blue growth will be measured

Our case studies indicate that the benefits, limits to, and opportunities for growth are scale-dependent in several directions, including both spatially and temporally (Lessons 1-3). The case studies demonstrated that marine social-ecological systems are dynamic, and that, once achieved, the collapse of blue growth can occur and recovery is not guaranteed (Lesson 4). There may also be trade-offs between users (Lesson 9), which can be scale dependent (Lesson 1). Therefore, it is important that blue growth agendas consider scale, and directly tackle how blue growth will be measured, prioritized, and maintained over time, space, and resource users. The blue growth agendas rarely explicitly considered scale beyond their utility as management units (e.g. sea basins/states; Table 3 in the main text).

B. Identify and engage stakeholders as early as possible in the decision-making process

Stakeholders, especially the local resource users themselves, have diverse perspectives and hold different types and amounts of knowledge that can support blue growth (Lesson 7), especially when engagement is equitable and occurs early on (Lessons 8 and 13). The importance of consulting and involving key stakeholders from the beginning is highlighted in both blue growth agendas (Table 3), however incorporation of the breadth of stakeholder and user perspectives is not as well-developed. By accommodating diverse perspectives and values, rather than assuming consistency among users, blue growth strategies can better facilitate the achievement of equity and equality.

C. Aim to align technological advancement and economic growth with other system attributes (e.g. social and cultural values, community supported regulations).

In the drive for blue growth, the case studies suggest local customs, cultures and traditional skills may be lost. Technological innovation and economic incentives can drive and/or support growth, but also may undermine other blue growth criteria more broadly (Lessons 2 and 3). However, there was also evidence that aligning technological advancement and wider economic growth with other system attributes that support blue growth, such as social systems (Lesson 6), environmental stewardship (Lesson 8), adequately enforced regulations and community buy-in (Lesson 13), may help to avoid pitfalls. The blue growth agendas (Table 3) highlighted some of these attributes (e.g., fostering regional cultural heritage, improving community resilience).

D. Be aware that not all blue growth criteria may be achievable simultaneously; have a plan for deciding trade-offs.

Case studies showed that it may be challenging or potentially impossible to meet all blue growth criteria at once (Lesson 14), or even the needs of all user groups (Lesson 9). Consequently, it is crucial blue growth agendas operate under the assumption that trade-offs will be required, and to carefully establish priorities and derive procedures for decision-making surrounding these trade-offs. The plans should also incorporate varying scales (Recommendation A) and a long-term, holistic perspective (Recommendations I and F, respectively). They should also be revisited routinely as conditions and the system change (Recommendation J).

2. Recommendations relevant to management that supports blue growth

E. Focus on facilitating equitable access, but recognise the potential for actions to impact user groups in different ways and mitigate appropriately.

Our case studies demonstrated that equitable access was not achieved by simply providing open access to a resource (Lesson 10), and careful consideration of resource group's needs, values and ability to access growth opportunities can be crucial (Lessons 7 and 9). Management may need to regulate access among groups in accordance with location-specific blue growth criteria, recognise that equity may not be achieved simultaneously across user groups, or that some groups will require additional support (Lesson 14; Recommendation D). The importance of equitable access is highlighted in blue growth agendas, e.g. the EU sets asides funds for reducing social disparities and supporting job creation, and the FAO states blue growth is a possible catalyst for poverty alleviation (Table 3). However, the complex nature of equity indicated by our case studies is not fully addressed.

F. Adopt a holistic view of the system based on the best available science, specifically include people.

To maintain blue growth and the associated benefits, our case studies indicate the importance of management and policy with a whole-system view that specifically includes people

(Lesson 12) and engages stakeholders (Lesson 7 and 8; Recommendation A). Further, many of the case studies demonstrated that a lack of scientific understanding can undermine growth (Lessons 1-5 and 12) and even result in system collapse (Lesson 2). The value of an ecosystem approach is demonstrated by its increasing adoption into policy (e.g., The EU's Integrated Maritime Policy), and a social-ecological perspective is generally embraced within the blue growth agendas. However, holistic management that includes a greater awareness of the human system as discussed here is not directly engaged with in the contemporary blue growth documents considered in the present study (Table 3).

G. Enact regulations that are enforceable, and align top-down and bottom-up controls

The historical case studies here demonstrated that regulations are required for blue growth to be maintained, but these often required enforcement and community buy-in to be successful (Lesson 13). Although strong top-down restrictions can facilitate effective management, they were most effective when aligned with bottom up controls like stakeholder support (either formal, e.g. via co-management structures, or informally, e.g. cultural norms). Case studies suggest simply investing capitol and time in developing strong regulations and policy may be insufficient. Supporting systems, environmental stewardship (Lesson 6 and 8), and alignment with a range of stakeholder perspectives and values (Lessons 7 and 9) can all help to foster community support and prevent behaviours that undermine blue growth irrespective of strong top-down controls. Collectively, our case studies indicate that instead of choosing between top-down or bottom-up controls the most effective management may result from alignment among them and with other aspects of the human community.

While contemporary blue growth agendas appear aware of the value of both top-down regulations and bottom-up initiatives, the benefits of alignment as we discuss here is not considered (Table 3). Additionally, whilst contemporary blue growth agendas highlight the need for appropriate regulatory frameworks, planning for their achievement at the state level is not mentioned.

H. Enact management that can respond and adapt to changing social-ecological conditions.

The case studies demonstrated the importance of looking beyond the current environmental and social conditions to include the ability of management to respond and adapt to change, whatever form that might take (Lesson 4). Further, they cautioned against assuming the achievement of blue growth equates to an equilibrium that requires less effort to maintain (Lessons 11-12). Instead, blue growth agendas should be constructed with dynamic systems in mind (Lesson 4). This is especially true given the influence of extrinsic drivers on blue growth (Lesson 5). Both the FAO and EU agendas promote adaptive management, but do not suggest how to adapt to different types of change (Table 3).

3. Recommendations after blue growth agendas are ratified.

I. Ensure that short-term gains do not undermine longer-term growth.

Short-term economic growth and improving technology can come with unanticipated future costs that destabilize longer-term blue growth (Lessons 2 and 3). Although there will always be social and political pressure to achieve benefits rapidly, the long-term consequences of these decisions must be given equal consideration. Blue growth agendas promote responsible growth and the need to ensure resources can be used by future generations, but they do not directly acknowledge the potential for short-term exploitation to undermine these longer-term goals (Table 3).

J. Ensure continuous monitoring of the system as well as extrinsic events and drivers, and that data are accessible and used to inform and ensure continued blue growth.

The achievement of recommendations that consider the importance of temporal scales (Recommendation C and I), and ability to respond to change (Recommendation H) will depend on successful and continued monitoring of the system. Our case studies indicate the importance of monitoring conditions, and this may be key to keeping abreast of the impacts of innovation (Lesson 11). Monitoring needs to be conducted at relevant scales (Recommendation C), be ongoing with an awareness of the wider system (Lesson 12), the potential for unpredictable change (Lesson 4) and the impacts of extrinsic factors (Lesson 5). Monitoring is considered in the EC blue growth agenda, although how extensive and well-resourced monitoring will be across member states is unclear. It is not mentioned in the FAO agenda (Table 3).