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research paper

Marine stocking in Chile: a review of past progress and future opportunities for enhancing marine artisanal fisheries

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DEVELOPING AND INTEGRATING ENHANCEMENT STRATEGIES TO IMPROVE AND RESTORE FISHERIES

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ABSTRACT.—Chile has a long history of restocking, stock enhancement, and translocation to support artisanal or small-scale fisheries; however, these programs have been scarcely discussed in the scientific literature. Here, we present a review of previous initiatives and discuss specific areas for future progress. We identified 204 releases across 117 different areas, involving 7 taxonomic groups and 22 species (20 marine and 2 freshwater). Marine stocking mainly occurred within the context of the spatial framework through which artisanal fisheries are managed [Management and Exploitation Areas for Benthic Resources (MEABR)], and over 60% involved translocation of wild individuals rather than release of hatchery-reared seed. While "stock enhancement" was the primary intention for most releases, it is unclear whether depleted spawning biomass or other recruitment limitations were the primary motivation, and few projects reported more than one stocking event. The echinoid *Loxechinus albus* and the gastropod *Concholepas concholepas* were the main target species. Only 6% of projects examined reported positive results that could be linked to releases, and none reported the use of tagging or analysis of costs or benefits. There are several areas for targeted development that should improve the social and economic outcomes from marine stocking activities. This synthesis provides a snapshot of marine stocking in Chile to date and highlights opportunities that are relevant to both Chile and other nations with substantial small-scale fisheries.

Aquaculture-based enhancement includes common human-mediated strategies used to restore or enhance the productivity of fisheries (Bell et al. 2008, Lorenzen et al. 2010, Grant et al. 2017, Kitada 2018). This practice generally involves releases of hatchery-reared individuals to enhance wild populations or reduce their decline by overcoming recruitment limitations or variability caused by overexploitation, oceanographic and climatic anomalies, pollution, and habitat degradation (Bell et al. 2008, Taylor et al. 2017). Aquaculture-based enhancement may be carried out for different purposes, which in turn require different management strategies. Three alternative strategies are often recognized (Bell et al. 2008, Lorenzen et al. 2013, Taylor et al. 2017): (1) restocking, where releases are primarily intended to rebuild the spawning stock of imperiled populations; (2) stock enhancement, where releases are intended to augment the natural supply of juveniles, to both improve harvest and spawning stock biomass; and (3) sea ranching, where releases support put, grow, and take operations, with a primary focus on harvest. The human-mediated relocation and releasing of wild-caught individuals, known as translocation or transplantation (Swan et al. 2016), is another strategy used to enhance fishery productivity (Caddy and Defeo 2003, Bell et al. 2008) and restore populations of threatened species (Fariñas-Franco et al. 2016, Swan et al. 2016, Wilcox et al. 2018).

Chile is a fishing nation; seafood production supports core economic and social outcomes for the population (IFOP 2019). Chile makes a significant contribution to global aquaculture production through salmon (924,000 tonnes) and mussel farming (402,000 tonnes; FAO 2020), and to global fisheries production with fishes, sea urchins, and seaweeds. For example, Chile accounted for the production of approximately 3.6 million tonnes of seafood in 2018, representing 2.2% of the total world production (FAO 2020); this included valuable benthic species of sea urchins (31,182 tonnes) and seaweeds (258,847 tonnes; SERNAPESCA 2018). Much of this production is derived from artisanal fishers. Artisanal or small-scale fishers are composed of divers, inshore fin-fishers and coastal gatherers harvesting on fishes, benthic invertebrates, and seaweeds. They mainly operate from deckless boats (<10 m in length) using dive gear and from the shore in the case of coastal gatherers (Gelcich et al. 2010). Within Chile, there are approximately 1546 artisanal fishing organizations, which support approximately 90,000 fishers across the country. Artisanal fisheries contributed about 32% of total Chilean production (1.2 million tonnes) in 2018, alongside industrial fisheries (31%) and aquaculture (37%; SERNAPESCA 2018).

Marine stocking has been extensively used to enhance the productivity of benthic artisanal fisheries in Chile (Bustos 1988, Castilla 1988). These activities have gradually increased over the past four decades, alongside declines in harvest of important species, but they have not yet been reviewed or critically evaluated in the international literature. Over recent years, juvenile hatchery production techniques have been developed for many exploited native species. These include invertebrates such as scallops (*Argopecten purpuratus*), clams (*Leukoma antiqua*), surf clams (*Mesodesma donacium*), sea urchins (*Loxechinus albus*), oysters (*Ostrea chilensis*), mussels (*Mytilus chilensis, Choromytilus chorus*), octopuses (*Enteroctopus megalocyathus*), but also seaweeds (e.g., *Sarcothalia crispata*, *Agarophyton chilense*, and *Macrocystis pyrifera*) and fishes such as Chilean silversides (*Basilichthys microlepidotus*) and flounder (*Paralichthys adspersus*; Silva and Oliva 2010, Cárcamo 2015, Rojas et al. 2016, Henríquez-Antipa and Cárcamo 2019, Uriarte et al. 2019). Many of these species support commercial-scale aquaculture production but are also candidates for enhancement initiatives for wild capture fisheries (Jerez and Figueroa 2008, Uriarte et al. 2019). Jerez and Figueroa (2008) reported that few release programs in Chile were well documented or monitored, and there was little conclusive evidence of success or positive impacts from releases. Despite this lack of evidence, artisanal fishers in Chile demand government-funded initiatives for the releasing of hatchery-reared organisms to improve fisheries yield in coastal areas (Cárcamo et al. 2014, Gelcich et al. 2017).

Considering the social importance of benthic artisanal fisheries, and the continuing expectation of fishers for release programs targeted at inshore coastal habitats, it is an opportune time to review past progress and future opportunities for enhancement in Chile. The socio-ecological context and management of fisheries in Chile is unlike many other western nations and provides a contrasting model through which fisheries enhancement may be employed to benefit small-scale fisheries. Here, we present a review of previous initiatives, commencing with the context of marine stocking in Chile, summarizing the projects to date, and discussing some of the current and future focal species. We identify some of the limitations of programs and conclude by identifying specific areas for future progress. This synthesis ultimately provides a snapshot of marine stocking in Chile and builds on this to highlight opportunities that are relevant to both Chile and other nations with substantial small-scale fisheries.

Regulation and Governance Provisions Relevant to Marine Stocking in Chile

Fisheries in Chile are managed under the Chilean General Law of Fisheries and Aquaculture (GLFA). Within the GLFA, restocking was initially conceptualized to increase the size or geographical distribution of a population using only artificial procedures (i.e., release of hatchery-reared individuals). Currently, the definition of restocking has been refined to imply a set of actions whose goal is to increase or recover populations of a certain hydrobiological species by natural and/or artificial means within their distributional range. It should be noted that the use of "restocking" here departs from contemporary definitions within the field of fisheries enhancement, such as stock enhancement, sea ranching, and translocation. While these are not defined in Chilean legislation, in the context of this review, restocking aligns primarily with the objectives of these three activities (rather than rebuilding of imperiled populations, which is implied in the contemporary definition of restocking).

Chilean legislation provides for restocking several specific regulatory frameworks (Table 1), including: (1) recreational fishing; (2) administration and management of restricted access fisheries, where restocking actions are considered within management plans; and (3) within a special management framework: Management and Exploitation Areas for Benthic Resources (MEABR, *see below*). In all cases, a restocking license must be obtained from the Undersecretary of Fisheries and Aquaculture, with compliance undertaken by the National Fisheries Service. Hereafter, we use "marine stocking" as a catch-all referring to the conventional types of aquaculture-based fisheries enhancement (restocking, stock enhancement) and translocation (which is not aquaculture-based).

In Chile, MEABR is a special network of marine territorial areas reserved for exclusive use by legally constituted organizations of artisanal fishers. These areas assign temporary territorial usage rights in fisheries (TURFs) for small-scale fishers, with particular species to be exploited within these areas specified in area-specific management plans. The Chilean MEABR network is the largest TURF-based co-management network worldwide, involving nearly 1000 sites ranging from 0.01 to 39 km^2 (average size = 1.5 km^2), covering about 1500 km^2 (Beckensteiner et al.

Table 1. Application areas for restocking in Chile according to the Chilean General Law of Fisheries and Aquaculture.

	Recreational Fisheries	Commercial Fisheries	MEABRs
Permitted sites	Marine waters Open access inland water bodies Private fishing areas	Within implementation area established in management plan	Within MEABRs
Main objective	Increase or restore wild populations (currently present or that occurred in the past)	Conservation and administration of commercially valuable resources	Recovery of commercially important species Increase reproductive potential
Origin of individuals	Native or feral individuals caught from wild populations Hatchery-reared GMOs individuals is forbidden	Donor populations located in OAA Hatchery-reared	Donor populations located in OAA Hatchery-reared From other MEABRs From seed collectors located in the same MEABR
Obligation to report results	No	No	Yes
Considerations about biogeographical range of target resources	Restocking must be done within biogeographical range of target resources (current or past)	Not established	Restocking must be done within biogeographical range of target resources
Property rights about restocked populations	Not established	Not established. Apparently applies legal principle of *res nullis*	Not established

2020). These areas generally represent sites that historically showed high abundance of desirable species (González et al. 2006, Molinet et al. 2010), and the co-management framework has been shown to maintain and increase resource levels (including size structure) compared with open-access areas (Defeo et al. 2016). However, in some MEABR there is evidence of declining densities for certain exploited species, including keyhole limpets *Fissurrella* spp., *L. albus,* and *Concholepas concholepas* (Beckensteiner et al. 2020).

Any marine stocking conducted within MEABR must satisfy certain criteria, including consideration of the abundance of species for selected sites and precautions to avoid sanitary risks associated with translocation (such as pests and disease). Marine stocking may be conducted using hatchery-reared individuals, individuals translocated from other MEABRs or obtained from seed collectors located within the same MEABR, with no restrictions on the number of releases that can occur using these approaches. Individuals can also be translocated from donor populations in other open-access areas (OAA), but these are restricted to only one unique release. Releases or translocations may only be conducted for target species that are outlined in the area-specific management and exploitation plan, with the primary objective of supporting the productivity of artisanal fisheries within MEABRs.

During the last three decades, the Chilean government has specifically targeted investment into marine stocking research, principally through open applications oriented to universities and research institutes. Most of these studies have focused on the development or improvement of hatchery production of several species, but due to the short-term nature of funding (i.e., grants of 2–3 years) it is challenging for projects to conduct monitoring of any releases over a sufficient temporal period. Marine stocking initiatives led by fisher organizations are most often funded by regional public agencies (and in some cases by private companies, such as a mineral resources company wishing to use marine stocking as part of an environmental mitigation strategy), and do not normally provide resources for monitoring and evaluation outside of the MEABR reporting requirements outlined above.

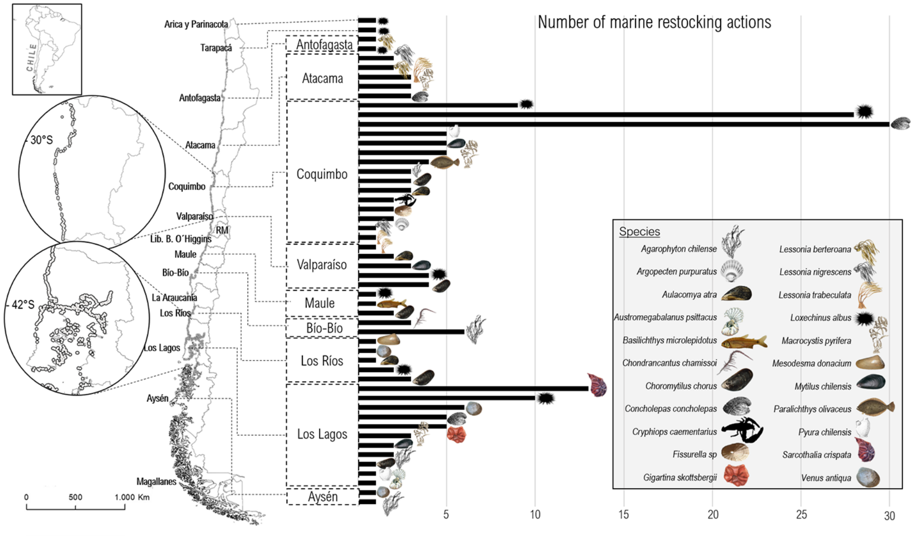

Figure 1. Number of marine restocking actions in Chile by region and species for the period 1987–2019. Small dots along the Chilean coastline represent the current Management and Exploitation Areas for Benthic Resources (MEABR) network; zoomed-in areas correspond to Coquimbo and Los Lagos regions.

Three Decades of Marine Stocking in Chile

In formulating this review, we examined information on both pilot-scale and large-scale releases and their outcomes (where available) reported in scientific publications, technical reports, management plans, and survey reports. Initiatives were categorized and analyzed considering: type of initiative (experimental, production, other), strategy (restocking, stock enhancement, translocation), species, geographic location, type of area, source (hatchery, aquaculture farms, wild stocks) and quantity of seeds or individuals stocked, stocking methods, evaluation or monitoring methods, and main outcomes.

A comprehensive review of scientific and grey literature revealed 204 release or translocation projects in Chile between 1987 and 2019, carried out across 117 locations among 9 geographic areas (Fig. 1). Of these, 22 areas had two releases, 8 areas had three releases, and 1 area had four releases. Seventy-nine percent of the projects occurred during the past two decades, and releases involved 7 taxonomic groups and 22 species (20 marine and 2 freshwater species; Table 2). Invertebrate species were the overwhelming target of projects to date, with the sea urchin *L. albus* and the muricid gastropod *C. concholepas* as the main target species. The most diverse taxonomic group released was seaweeds (8 species) followed by bivalves (6 species; Table 2). Most of the cases were distributed in areas located in the Atacama and Coquimbo regions (North-central Chile) and Los Lagos region (Southern Chile), and 89% of releases occurred within MEABRs (the remaining 11% were conducted within OAA; Fig. 1). Of these 204 projects, 15% were research-based or experimental, carried out by universities or research centers; the remaining 85% were undertaken for the purpose of enhancing harvest by artisanal fishers.

Table 2. Summary of species and marine stocking activities reported in Chile between 1987 and 2019. Numbers except for the column of total individuals and range of individuals released indicate number of stocking activities. * = freshwater species. ** = expressed as fresh weight in kg.

Species	Total Releases	Total Individuals Released (Range)	Seed Source			Stage		Type of Initiative		Type of Area	
			Wild	Hatchery	Marine Farm	Juvenile	Adult	Experimental	Production	MEABR	OAA
Echinoderm											
Loxechinus albus	57	7,672,000 (1,000–1,000,000)	32	25	- - -	29	28	14	43	51	6
Gastropod											
Concholepas concholepas	38	808,000 (5,000–60,000)	38	- - -	- - -	3	35	- - -	38	38	- - -
Fissurella sp.	2	131,000 (6,000–125,000)	2	- - -	- - -	- - -	2	- - -	2	2	- - -
Bivalve											
Choromytilus chorus	13	3,492,000 (3,200–1,400,000)	9	- - -	4	5	8	- - -	13	13	- - -
Mytilus chilensis	10	31,735,000 (140,000–21,000,000)	2	- - -	8	5	5	- - -	10	10	- - -
Leukoma antiqua	8	3,928,000 (7,000–1,000,000)	4	4	- - -	4	4	- - -	8	8	- - -
Aulacomya atra	6	3,233,000 (3,200–1,400,000)	3	- - -	3	5	1	- - -	6	6	- - -
Argopecten purpuratus	2	150,000 (50,000–100,000)	- - -	2	- - -	1	1	1	1	1	1
Mesodesma donacium	2	700,000 (200,000–500,000)	2	- - -	- - -	- - -	2	1	1	1	1
Seaweed											
Sarcothalia crispata	14	38,500** (500–4,160)	12	1	1	5	9	1	13	13	1
Agarophyton chilense	12	332,000** (500–90,700)	2	- - -	10	- - -	12	- - -	12	12	- - -
Macrocystis pyrifera	7	34,700 (100–12,000)	4	3	- - -	5	1	3	4	4	3
Gigartina skottsbergii	5	1,950** (200–1,500)	4	1	- - -	1	4	- - -	5	5	- - -
Lessonia trabeculata	5	59,000 (1,000–48,000)	1	4	- - -	4	1	- - -	5	5	- - -
Chondrancantus chamissoi	3	2,800** (500–1,800)	3	- - -	- - -	- - -	3	- - -	3	3	- - -
Lessonia nigrescens	3	300 (100)	2	1	- - -	2	1	3	- - -	- - -	3
Lessonia berteroana	3	23,300 (300–20,000)	3	- - -	- - -	1	2	- - -	3	3	- - -
Tunicate											
Pyura chilensis	6	35,100** (1,300–18,200)	4	- - -	2	5	1	- - -	6	6	- - -
Crustacean											
Austromegabalanus psittacus	1	2,000**	1	- - -	- - -	1	- - -	- - -	1	1	- - -
Cryphiops caementarius *	2	50,000 (15,000–35,000)	- - -	2	- - -	2	- - -	2	- - -	- - -	2
Fish											
Basilichthys microlepidotus *	1	4,000	- - -	1	- - -	1	- - -	1	- - -	- - -	1
Paralichthys adspersus	4	140,000 (5,000–70,000)	- - -	4	- - -	4	- - -	4	- - -	- - -	4

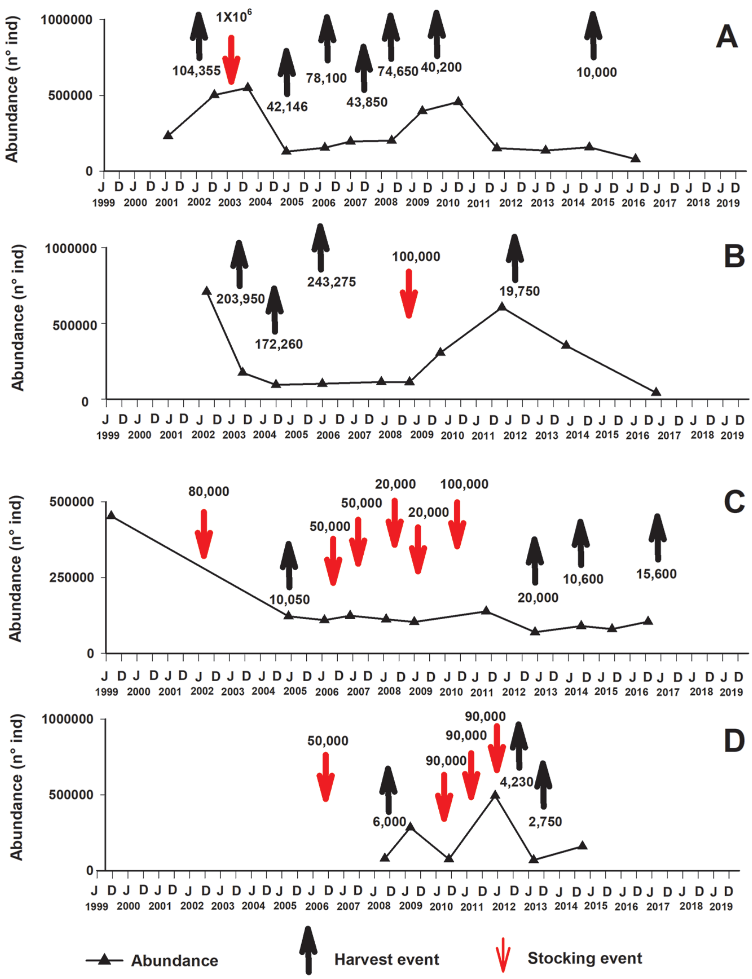

Figure 2. Total abundance of sea urchin *Loxechinus albus* in four Management and Exploitation Areas for Benthic Resources (MEABRs). The red arrows indicate marine stocking releases and quantities of released individuals while the black arrows indicate the harvested individuals reported at various time points. (A) Pisagua Bay, (B) Pan de Azúcar Island, (C) Quintay, and (D) Los Vilos.

Many projects (59%) reported the release of adults, with the remaining dealing with juveniles. The number of individuals per project varied between about 21,000,000 (mussel *M. chilensis* juveniles) and 100 individuals (*Lessonia nigrescens* and *M. pyrifera* adults), with wild stocks being the source of seed for 63% of the projects (sourced from either MEABRs or OAA), 24% used hatchery-reared individuals, and 14% sourced seed from marine farms (i.e., commercial mussel farms; Table 2). Finally, 8% of projects incorporated additional structures to assist survival of released individuals, such as cages or artificial reefs.

Of the projects reviewed, few (25%) conducted monitoring that was quantitatively reported (e.g., estimates of abundance or size structure) prior to releases, with even fewer projects (15%) reporting population data following release. Six percent of projects reported an increase in abundance that was likely to be associated with stocking. None of the projects examined reported the use of tagging methods for monitoring or provided information on costs or any economic analyses. Furthermore, the motivating factors underpinning release (such as recruitment limitation) was not clear for most projects. Because most projects occurred within the MEABR network, and because the original and main aims of MEABR co-management regime are oriented to maintain or enhance fishery yields, it is reasonable to assume that the intention of most projects was stock enhancement or sea ranching, with fishers seeking to harvest some proportion of released individuals. Nonetheless, the paucity of well-designed monitoring programs in Chile severely constrains our understanding of the outcomes of stocking, interactions of released individuals with the recipient ecosystem, and incremental adaptation of strategies over time to maximize release success.

Focal Species Released in Chile

As highlighted above, releases are primarily carried out within MEABRs, and accordingly the focal species for marine releases in Chile reflect those species that are most desirable for artisanal fishers. These include the sea urchin *L. albus*, the gastropod *C. concholepas*, and the mussel species *M. chilensis, C. chorus*, and *Aulacomya atra* (Table 2), all of which have established export markets. The first two species are distributed along the entire Chilean coast and represent the two most socioeconomically important artisanal fisheries but have both shown signs of overexploitation (Castilla 2010). Here, we briefly outline some previous outcomes from marine stocking of these species (primarily *L. albus*) and highlight some areas for future attention.

Sea Urchin *Loxechinus albus*.—*Loxechinus albus* has been subject to decades of heavy exploitation in Chile, exclusively by artisanal fishers (Vásquez 2020). This has contributed to a decline in overall landings between 2002 (60,166 tonnes) and 2018 (31,182 tonnes). Advances in larval development, seed production, and research on nutritional requirements to enhance growth and gonad quality has meant there is potentially a reliable source of seed to support release programs (Olave et al. 2001, Cárcamo et al. 2005, Cárcamo 2015), but translocation of wild seed is also employed. Releases have frequently been used for short-term management in Chile putatively to enhance productivity of wild stocks (Table 2), but release activities generally involve a diversity of approaches and animals are not usually marked for later identification and evaluation. This has hindered comparison among regions and the identification of factors that ultimately influence release success for the most widely stocked species in Chile. This has complicated the distinction between the effects of stocking on the fishery and the natural dynamics of the wild stock.

Sea urchins are most extensively released or translocated within MEABRs, with the tally of releases to date amounting to almost 8,000,000 individuals, dominated by hatchery reared juveniles in central-northern Chile. To date, there has been little research on either the ecological impacts of stocking or strategies to improve survival and contribution to the fishery. *Loxechinus albus* is an active grazer on kelp (Vásquez 2020), and it is possible that the stocking or translocation may adversely impact kelp recruitment, which would further exacerbate the impact of current overharvesting of kelp species (Krumhansl et al. 2016). Kelp is not yet a major focal

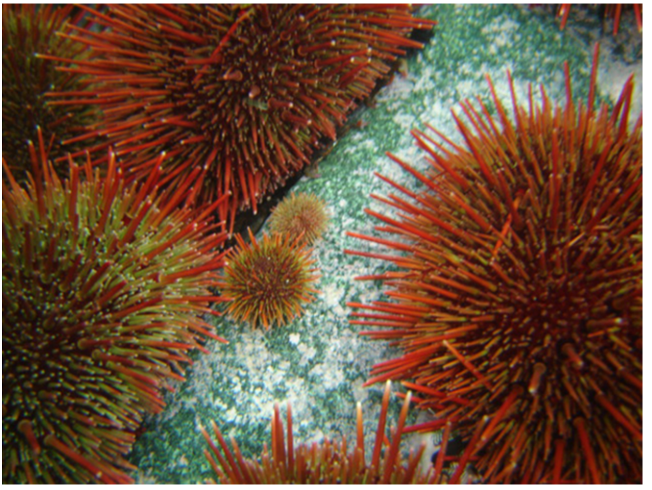

Figure 3. Release of sea urchin *Loxechinus albus* adults carried out in Los Vilos area (Courtesy of the Ñague Fisher's Cooperative).

species for releases (compared to invertebrates), however, as we discuss below, technology for production of propagules has recently improved to the point that such programs may be supported (Westermeier et al. 2014b, 2017).

Releases of *L. albus* have shown variable success, but the lack of tagging techniques to identify stocked individuals, and the overall lack of targeted monitoring of release programs, has constrained our comprehension of the potential factors that contribute to this variability. For example, consider releases of *L. albus* across four MEABRs within northern and central Chile (Fig. 1), for which sea urchin survey data were available. In Pisagua Bay (19.59°S, 70.21°W), a single release of 1,000,000 juveniles occurred in 2003 (Fig. 2A); however, stocking was followed by a drastic reduction in total abundance in the following year which was accompanied by a comparatively low harvest for this area. Personal observations from local fishers indicated that there was an increase in the density of rockfish, mainly *Pinguipes chilensis,* predating on the stocked juveniles, which may have contributed to these patterns. In Pan de Azúcar Island (26.16°S, 70.67°W), a single release of 100,000 juveniles occurred in 2009 (Fig. 2B) and during the following years, abundances within the MEABR increased to 500,000 individuals, but this was accompanied by a comparatively small harvest before the population declined again. It was thought that illegal fishing may have contributed to these patterns. In Quintay Bay (33.19°S, 71.70°W) following a substantial population decline, there were repeated releases over 5 years with minimal harvest, however, the population continued to show declined abundance (Fig. 2C). Finally, a different approach was employed in Los Vilos (31.89°S, 71.50°W), where the strategy was informed by local knowledge and involved translocation of adult sea urchins from more productive areas nearby (Fig. 3), again with minimal harvest. Releases were accompanied by a substantial increase in abundance (Fig. 2D), and anecdotal evidence also indicated that new recruitment had occurred in stocked areas (likely from translocated adults). These results led to increased interest in the translocation of adult spawning stock by fishers in other MEABRs to improve yield, and a similar approach is also under consideration for the commercially important gastropod *C. concholepas.*

These case studies exemplify the diversity of outcomes from releases and the difficulty in assessing outcomes from marine stocking. Releases of juvenile urchins appeared uncoupled to patterns in abundance and the magnitude of fisheries yields. In contrast, translocation of adult urchins in Los Vilos is likely to have led to reproductive activity which facilitated stock rebuilding, but this cannot be demonstrated unequivocally with the data collected. Unfortunately, the real contribution of stocking and translocation activities can rarely be assessed in Chile, and this is evident in the outcomes reported here. Practical observations suggest that habitat suitability, density dependence, and quality of hatchery-produced seed are the proximal factors influencing the outcomes from juvenile releases. Targeted monitoring before and after release is essential to assess the relative influence of these factors in future releases and identify which strategies are most likely to improve fishery outcomes.

Chilean Abalone (Known as "Loco") *Concholepas concholepas*.—The gastropod *C. concholepas* is a top predator and key component of inshore food webs along the Chilean coast. During the early 1980s signs of depletion became evident, and managers have implemented several fishing closures since 1985. This crisis was one of the factors that led to the development of the extensive TURF policies in place today (Beckensteiner et al. 2020).

Similar to *L. albus*, releases have been concentrated in central-northern Chile, with numbers totaling approximately 808,000 individuals. Larval cultivation remains a significant bottleneck for this species, so most of these releases have involved the translocation of adults among MEABRs. As aquaculture technology improves and production upscales, this may provide a basis for expanded releases of hatchery reared individuals (Manríquez et al. 2008, Uriarte et al. 2019).

Mussel Species.—Mussel production in Chile primarily involves culture of *M. chilensis*, and production has increased substantially over the past 15 years to the point that Chile is among the leading global exporters (Gonzalez-Poblete et al. 2018). *Mytilus chilensis* is distributed from central Chile (about 38°S) to southern Patagonia (about 53°S), although 97% of the production is concentrated in Los Lagos Region (approximately 41°S–43°S). Chilean production is driven by collection of large numbers of wild seed, which is usually carried out by artisanal fishers. However, recent studies on recruitment inputs in mussel beds suggest that seed collection of this magnitude may have substantial negative effects that threaten the viability of existing mussel beds (Molinet et al. 2017).

While mussels have only been the target of a small proportion of overall releases, there is potential with these taxa to rebuild severely impacted mussel beds and to create additional mussel beds in new areas to supply seed requirements for aquaculture. Existing sources of seed already exist (Fernández et al. 2018), but the strong demand for wild-collected mussel seed probably exceeds the level that existing beds can sustainably supply.

Areas for Progress

General Comments.—While Chile has a long history of conducting releases intended to improve fisheries productivity, previous work has set a precedent that departs from internationally accepted conventions on conducting releases in a responsible fashion (Bell et al. 2008, Lorenzen et al. 2010, Leber 2013, Grant et al. 2017, Taylor et al. 2017, Kitada 2018, Coleman et al. 2020). This is problematic, as current activities in Chile often fail to recognize the scientific developments in the field that have arisen over the past few decades, and thus releases may at times be conducted under inappropriate scenarios or have poor or unknown outcomes. This is in part due to the absence of specific mandates for implementation of marine stocking activities within the regulatory or policy framework, but is also exacerbated by the fact that artisanal fisher organizations frequently conduct these activities with limited interaction with scientists in the design, monitoring, or evaluation.

The principles of responsible marine stocking are well established and the literature contains many examples which highlight the factors that should be considered in these projects, such as: prioritizing species; background investigations on species biology, wild stocks (i.e., genetics), and habitats (i.e., habitat requirements and carrying capacity); development of hatchery seed quality; and pre- and postrelease research, monitoring, and evaluation. Additionally, this responsible approach includes stakeholder engagement and the development of accountable decision-making processes, adaptive management, and economic (and/or social) evaluation. Thus, we do not discuss these general ideas in detail here, other than to point out that Chilean projects would clearly benefit from improved attention in this area. Rather, we highlight some explicit areas for consideration in the Chilean context, and briefly highlight some opportunities for future development.

Marine Stocking in the Context of Chilean TURFs.—Selection of appropriate areas to release hatchery-reared or translocated individuals is an important consideration in any marine stocking endeavor (Bell et al. 2008, Lorenzen et al. 2010, Taylor et al. 2016, Puckett et al. 2018). Lipcius et al. (2008) highlights that it is important to distinguish between self-sustaining populations in "source" habitats and sink populations receiving recruits from elsewhere. Stocking of sink areas may enhance fisheries productivity but will require ongoing releases. If stock rebuilding is desirable, releases targeting population source areas should be considered (Grant et al. 2017, Puckett et al. 2018).

At first consideration, the MEABR network provides an ideal framework for releases of benthic species with low mobility by local user groups, as it provides TURFs for particular fishers, has a lower chance that animals will emigrate to other areas, and thus reduces externalities. However, the areal extent of MEABRs is often much smaller than the extent of species sub-populations, which makes population management within these areas challenging (Molinet et al. 2010). Consequently, conducting marine stocking within this framework requires careful consideration of population dynamics and connectivity, which historically has not been the case, and likely contributes to the variable impact of releases observed among seemingly similar MEABRs (Fig. 2, *see above*).

Recent research has resolved patterns in dispersion, connectivity, and recruitment across the MEABR network for focal species of artisanal fishers, such as *C. concholepas* and *L. albus* (Garavelli et al. 2016, Ospina-Alvarez et al. 2018, Blanco et al. 2019). This creates the opportunity to better understand source-sink dynamics among MEABRs and the benthic habitats therein, and identify whether releases are appropriate in different areas when considered alongside other management strategies. Ultimately, developing this knowledge base and employing appropriate modelling will mean that releases can be targeted directly into recruitment limited niches within individual MEABRs, and opportunities can be identified for targeted releases of additional desirable species. For example, recent research suggests small-scale releases of translocated adults or hatchery-reared individuals of the gastropod *Trochus niloticus* may have potential for enhancing populations within a network of small-scale spatial management units (Dolorosa et al. 2013). Improved consideration of individual MEABRs within the broader metapopulation for desirable species will help to make full use of this unique spatial management network, for enhancement of fisheries through marine stocking.

Further, recent amendments to the GLFA and associated regulations have sought to improve integration of aquaculture into broader aquatic resource management. The existing MEABR framework has been identified as a vessel through which small-scale aquaculture may be developed, with the aim of diversifying livelihoods of artisanal fishers (Henríquez-Antipa and Cárcamo 2019, Sepúlveda et al. 2019). Diversification of income and additional skills and training may lower the economic impact of poor harvest years for fishers. But most importantly, while the risks and benefits of expanded small-scale aquaculture need to be investigated, this arrangement creates an opportunity for integration of seed production, release, and harvest by artisanal fisher organizations that hold rights to MEABRs.

Better Integration of Marine Stocking with Other Management Approaches.—Artisanal fishers consider marine stocking to be the best strategy to improve the productivity of the MEABR system (Gelcich et al. 2017). Best practice, however, recommends an integration of marine stocking with other management measures (Leber 2013, Kitada 2020), and this is exemplified in a recent analysis of stock enhancement in Japan which showed that increases in seaweed communities, recovery of nursery habitat, and fishing restrictions had a greater impact on stock recovery than marine stocking (Kitada 2020). More conservative assessments suggest that the use of hatchery-reared individuals to improve productivity of a depleted stock should only occur when other more traditional management measures have failed and recruitment limitation is present (Grant et al. 2017).

Overall, there has been minimal integration between marine stocking and other more conventional management approaches in Chile. This may be due in part to the fact that natural recovery often occurs over extended time frames, which may not be socially or economically acceptable to artisanal fishers, whereas marine stocking is perceived to lead to more immediate effects. It is likely that some combination of these approaches will provide the best outcomes for artisanal fishers, providing some immediate enhancement (if stocking is done responsibly) as well as recovery over the longer-term. The potential of such an approach for Chilean artisanal fisheries is seen in modelling of alternate management strategies for *L. albus* within a small (104 ha) MEABR (del Campo Barquín 2002). The outcomes suggested that solely stocking animals was economically unfeasible, but a combination of adaptive enhancement activities and flexible exploitation maximized harvestable biomass and economic returns. Strong variability or failure of recruitment has been reported for several commercial and target species for marine stocking in Chile (Navarrete et al. 2002, Aburto and Stotz 2013), which is likely a result of environmental variation influencing spawning, advection, and/or larval survival (Lipcius et al. 2008, Szuwalski et al. 2015). It is these cases which would most benefit from targeted releases into

MEABRs, but such actions require a detailed understanding of reproduction and connectivity, and are best accompanied by actions to ensure the sustainability of the broader spawning stock over the longer term.

Improving Translocation Protocols.—Translocation is increasingly used to conserve species and ecosystems under threat from habitat fragmentation and climate change (Fariñas-Franco et al. 2016, Swan et al. 2016). Translocation of animals also has been widely reported within the stock enhancement literature (Bell et al. 2008, Green et al. 2010), and evaluation has shown increased profits or yields in high-value species such as the lobster *Jasus edwardsii* (Gardner et al. 2015) and the sea urchin *Centrostephanus rodgersii* (Blount et al. 2017), often with minimal environmental impacts (Green et al. 2013).

The approach to marine stocking in Chile is unique in that more than half of the projects identified have employed translocation of wild individuals, rather than release of hatchery-reared individuals. Most of these projects involve the transfer of individuals from OAA into MEABRs, or among MEABRs. The preference for translocation is often due to the improved survival of wild seed and is often necessary due to the absence of a local source of hatchery-reared seed for desirable species. Most significantly, translocation actions often arise from implementation of local traditional knowledge of artisanal fishers to avoid potential density dependent impacts on recruitment and growth (Tegner and Dayton 1977, Stotz et al. 1992).

Despite translocation apparently representing a comparatively low-risk form of enhancement, at present these locally-driven activities may not fully recognize factors that are important in more conventional hatchery-reared releases (such as stock structure, potential ecological and genetic impacts, and transfer of disease and invasive species). The expanding literature on genetic structure and spatial genetic connectivity of desirable species in Chile (Cárdenas et al. 2016, Guillemin et al. 2016, Blanco et al. 2019, Astorga et al. 2020, Schreiber et al. 2020) provides a novel information base which can be integrated with traditional knowledge in the design and development of translocation strategies. This will help to lower the risk of unanticipated adverse outcomes, but may also help to optimize efforts, which at times can involve physical collection and movement of 10,000–100,000s of individuals at a time.

Foundation Species as Focal Targets for Restoration.—Seaweeds are of significant importance for Chile's economy and culture (Henríquez-Antipa and Cárcamo 2019). These foundation species also have an important ecological role, but excessive and IUU harvest have contributed to ongoing declines, with little evidence to suggest there will be future recovery. Calls for restoration actions are likely to increase in the near future. This is fueled by increasing worldwide interest in stocking as a form of habitat restoration to combat increasing loss of foundation species (e.g., seagrass, oysters, kelps, mussels) and to restore associated ecological functions (Layton et al. 2020) and harvest (Claisse et al. 2013).

Chilean kelps support a vast biodiversity and marine stocking has the potential to restore these communities and ecosystems. Several studies have shown that at least six species of fishes (including sharks) and approximately 50 taxa of invertebrates depend on the habitat provided by kelps to reproduce and thrive (Thiel and Vásquez 2000, Vásquez and Vega 2005, Uribe et al. 2015, Trujillo et al. 2019, Villegas et al. 2019). Theoretically, kelp stocking will not only improve harvest of kelp species for export, but also support recovery and/or enhancement of other desirable species for artisanal fisheries, such as sea urchins and gastropods. This potential "double benefit" suggests that kelp stocking represents an opportunity which sits firmly within the broader "ecosystem approach" to management that is intended by the GLFA. Coupled with the initiatives outlined above, financial subsidies have been offered to promote the cultivation and stocking of kelps by artisanal fishers and small-scale farmers since 2016. The intent behind these subsidies is to enhance the available biomass of ecologically and economically valuable seaweeds, however, projects to date have shown an almost exclusive preference for *Agarophyton chilense*, which is the only seaweed that has been cultivated on a commercial scale in Chile. Again, this opportunity has a firm basis in the artisanal MEABR network, and these areas have been clear targets for organizations wishing to access the financial subsidies for this work.

Governance and Fishers' Engagement.—Research has shown that the success of restocking is more likely when the community is committed to doing so prior to stocking events and is involved in the process (Garaway et al. 2006). Lorenzen et al. (2010) pointed out three core steps in the restocking process: facilitation of the process itself, stakeholder inputs, and scientific assessment.

Despite the lack of evidence of positive impacts of stocking actions found in this review, apparently, artisanal fishers have positive attitudes towards marine stocking. Garlock and Lorenzen (2017) documented that inshore anglers in Florida were generally supportive of stock enhancement but largely unaware of the risks and tradeoffs inherent to this management measure. Considering most stocking actions occur in the MEABR co-management network, an active involvement and engagement of fishers could be assumed (Gelcich et al. 2010). Given the different and potential governance arrangements of the Chilean MEABR network (e.g., surveillance, enforcement, co-management, restriction of access and harvest, establishment of local rules; Gelcich et al. 2010, 2017), it has the potential for developing successful enhancement programs. Additionally, fishers' knowledge should be complemented through education about the latest science and developments in the restocking field including the costs, benefits, and potential impacts. Educating fishers as to the importance of assessing stocking activities via mark and recapture and genetic techniques is paramount.

Conclusions

Broadscale declines in abundance, yield, or revenue from fisheries are the usual motivations for implementation of marine stocking actions across the world (Lorenzen et al. 2010), and Chile has not been an exception. Marine stocking in Chile is strongly oriented to the MEABR network, particularly the enhancement of harvest and incomes for artisanal fishers targeting benthic invertebrate and kelp species. Translocation of wild individuals is a slightly more common approach than hatchery releases, drawing on local knowledge and carried out by artisanal fishers themselves. Although Chilean marine stocking history is not young (more than three decades old), the scientific foundation of this activity is yet to mature in Chile. This likely results in suboptimal outcomes from marine stocking efforts, and a poor information base from which to implement adaptive management and improve practices over time. Current activities suffer from an incomplete understanding of coastal ecosystem dynamics and the influence of these dynamics on the MEABR network.

At present, research funding favors work to develop or improve hatchery production of target species. Scientific evaluation of outcomes and impacts of marine stocking are rare and confined to experimental studies and monitoring of survival and growth of released individuals. There are some discrete examples which demonstrate positive outcomes following stocking, including the kelp species *M. pyrifera* and *Lessonia berteroana* (Vásquez and Tala 1995, Vásquez et al. 2014, Westermeier et al. 2014a, 2016), scallop *A. purpuratus* (Avendaño and Cantillánez 2003), and the sea urchin *L. albus* (Bustos et al. 1991). Clearly, the funding base for supporting research needs to be improved and concerted efforts made to (1) improve knowledge of reproduction, recruitment, and connectivity within the MEABR network; (2) conduct basic research on potential genetic and ecological risks including translocation; (3) develop and improve stocking strategies; (4) evaluate releases, including the use of tags and the measurement of ecological and socio-economic outcomes and impacts; and (5) understand current fishers' knowledge on marine restocking to improve education and engagement efforts. Fishers, practitioners, and scientists would benefit from a locally-relevant review that deals explicitly with these research priorities within the context of Chilean species, fisheries, and ecosystems.

The current network of fishery management and conservation areas based on territorial use and co-management principles constitutes a great opportunity to develop evidence-based marine stocking programs in a more holistic spatiotemporal context. While this opportunity is not unique to Chile, there are few examples from anywhere which describe marine stocking within a similar framework (Meo 2012, Pickering and Hair 2012). While this framework provides a strong platform for a community-based, integrated aquaculture, enhancement, and fishery system, there is much to be gained from forming strong partnerships between the artisanal fisher organizations involved and fisheries ecologists. The resultant knowledge transfer will provide the nexus of local and scientific knowledge necessary to optimize marine stocking activities and maximize the resultant social and economic outcomes. Finally, integrated fisheries enhancements that involve harvested foundation species such as kelps potentially have multiple benefits, and the dividends of stocking these species are yet to be fully realized.

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