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Are Territorial Use Rights in Fisheries (TURFs) sufficiently large?

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ABSTRACT

Territorial Use Rights in Fisheries (TURFs) are gaining renewed attention as a potential tool for sustainable fisheries management in small-scale fisheries. This growing popularity comes despite the fact that there are still unresolved questions about the most effective TURF designs. One of the key questions is the role of TURF size in their efficacy both from ecological and social standpoints. This study explores the expected effects of existing TURF sizes on yields for TURF systems in Chile, México and Japan. The expected effect of larval dispersal and adult movement on yields was simulated for TURFs in each system. The results show that the analyzed TURF systems fall into three main categories: (a) TURFs that are of adequate size to eliminate the expected negative effects of both adult and larval movement, (b) TURFs that are large enough to eliminate the expected negative effects of adult movement, but not the effects of larval dispersal, and c) TURFs that are too small to eliminate the expected impacts on yield of both adult and larval movement. These analyses suggest that either existing models of TURF performance are incomplete or that there is significant scope for improved performance with altered TURF designs. Considering these alternatives, empirical evidence from the TURFs deemed too small suggests that complementary management tools can enhance TURF performance when natural or social constraints prevent the construction of TURFs of optimal size.

1. Introduction

Territorial use rights in fishing (TURFs) provide one or more fishermen with exclusive access to particular fishing grounds. They have existed for centuries in many coastal areas around the world and have been shown to be successful as a form of access right, particularly for small-scale fisheries [16, 29, 44]. The successful management of small-scale fisheries is often achieved by co-management arrangements [8,12], requiring a strong capacity for self-organization [17,28]. By securing exclusive access to marine resources, TURFs can enable the conditions necessary for the development of successful co-management schemes [16, 17, 30, 39]. As a result, TURFs are gaining increasing attention as an instrument for fisheries management that could be applied far more broadly.

Despite these successes, the relationship between specific TURF characteristics and performance is poorly understood. Theory suggests that for TURFs to successfully enable the social conditions that lead to sustainable harvests, fishermen should have the necessary security in the exclusivity of access [39]. This exclusivity is determined to a large degree by the ratio of TURF size to targeted species movement. Therefore, TURF size can potentially have large impacts on social and biological outcomes. Previous efforts [46] have looked at the theoretical effects of TURF size on yield, showing that larger TURFs should decrease the spillover of adults and larvae to surrounding areas and thereby create greater incentives for TURF owners to take actions that enhance longer term yields. These theoretical projections suggest that TURFs may need to be tens of kilometers or more in length to generate robust and sustainable returns. Yet, existing TURF systems were designed based upon other criteria: e.g., the location of traditional fishing grounds, geographic characteristics, or legal mandates [5,40]. This raises several questions: are existing TURFs consistent with emerging design theory? If not, does TURF performance vary predictably with TURF size? Alternatively, can the expected limitations of small TURFs be overcome through other mechanisms (e.g., cooperation across TURFs)?

To explore these questions, relationships between fishery outcomes and the size of TURFs in Chile, México and Japan were analyzed. The model from White and Costello [46] was used to simulate the expected effect of spillover (both larval and adult) on yields for TURFs of varying size. The results show that existing TURF systems are often large enough to eliminate the deleterious effects of adult movement, but are typically too small to fully mitigate the theoretical effects of larval

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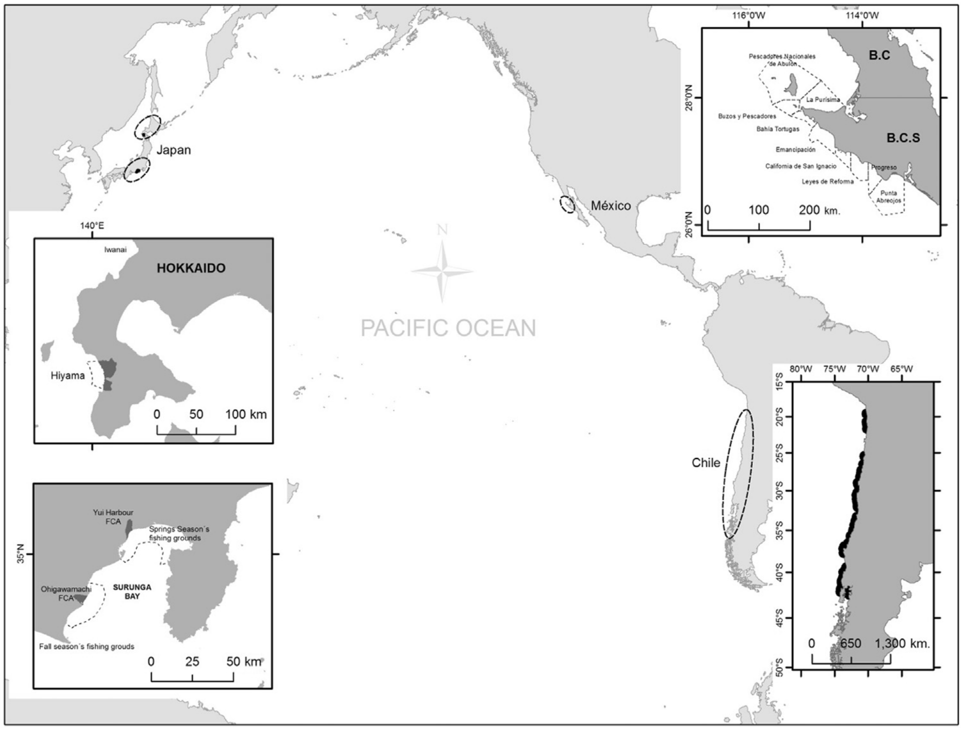

Fig. 1. Location of the case studies analyzed in this study.

dispersal. This is often a consequence of the presence of strong social and geographic constraints when selecting the size of TURFs [31]. However, the modeled losses in yields due to spillovers do not necessarily align with empirical evidence of successful management. Two potential reasons for this discrepancy – cooperation and imperfect information – are explored, thereby identifying important areas for extensions to current TURF design theory.

1.1. Case studies

The case studies were selected from the three largest existing systems of TURFs - México, Japan and Chile (Fig. 1). In all cases, attention was restricted to TURFs currently in operation. The analysis examines species that are the main target of the TURFs and therefore the main drivers of their design.

1.1.1. México

The study is focused on The Pacifico Norte fisheries and fishing cooperatives, located along the northern part of the Pacific side of Baja California Sur as well as Cedros and Natividad Islands. These cooperatives form part of a larger federation (FEDECOOP) and were granted exclusive fishing zones in 1992 [22]. The TURFs provide the cooperatives with exclusive access for 20 years (with the possibility of renewal) to several resources. Spiny lobster (*Panulirus interruptus*, Palinuridae) and abalone (*Haliotis fulgens*, Haliotidae) are the most economically important [22]. The Marine Stewardship Council (MSC) certified the sustainability of the spiny lobster fishery in 2004 [21].

1.1.2. Japan

Two different TURF systems from Japan were analyzed: the walleye pollock (*Theragra chalcogramma,* Gadidae) TURFs in the Hiyama region, located around southwestern Hokkaido island, and the sakuraebi (*Sergia lucens,* Sergestidae), TURFs in Suruga Bay, central Japan. The TURFs in the Hiyama region corresponds to the exclusive fishing grounds (or sections) of the Nishi and Esashi-Kaminokuni cities. This region is the main spawning ground for the northern Japan Sea stock of walleye pollock. The TURFs in Suruga bay provide exclusive access to the sakuraebi, a meso-pelagic shrimp [20] that appears to be sedentary in this region. The TURFs belong to the Yui Harbor Fishery Cooperative Association (FCA) and the Ohigawamachi FCA. This fishery is one of the most valuable in Japan [44,45].

1.1.3. Chile

TURFs were included in Chile's legal framework for the management of benthic resources in 1991, and they have been key in recovering collapsed fisheries. Studies have found a dramatic increase in abundance and individual size of targeted species compared to open access areas [16]. Currently Chile has 707 TURFs in different stages of operation. The analysis is focused on TURFs that manage loco (*Concholepas concholepas,* Muricidae) one of the most economically important resources for artisanal fishermen [7] and the main driver of the creation of TURFs system [16]. Operative TURFs ("estado operativo") were identified using data from SUBPESCA [43].

2. Methods

The two patch bio-economic model from White and Costello [46] was applied to each of the case studies. In the model, the patches (i and j) represent TURFs that are owned by fishing cooperatives, each of which perfectly coordinates its harvest decisions within the TURF, allowing it to act as a single agent. Each agent selects the escapement level (N) to maximize the yield within his patch. The agents select harvest simultaneously and non-cooperatively, taking the other owner's decision as given. The analysis is focused on the resulting Nash equilibrium, highlighting the consequences of competitive behavior expected to result from high levels of spillover (see [46] for further details).

In order to categorize the performance of TURF systems, the yields that are expected to arise when each TURF owner harvests non-cooperatively with respect to the adjacent TURF were calculated. The expected yields were computed under three spillover scenarios: no spillover, larval dispersal only, and adult movement only. Comparing yields in these scenarios permits attribution of losses in yield to the two spillover sources and allows for categorization of the systems of TURFS on the basis of that decomposition.

Table 1
TURF systems analyzed in this study.

Country	TURF System	Main targeted species	Average TURF along shore length (km)
México	Pacífico Norte	Green Abalone *Haliotis fulgens* (Haliotidae)	44.25
México	Pacífico Norte	Spiny Lobster *Panulirus interruptus* (Palinuridae)	44.25
Chile	TURFs targeting loco (operative state)	Loco *Concholepas concholepas* (Muricidae)	1.63
Japan	Suruga Bay	Sakuraebi *Sergia lucens* (Sergestidae)	27.5
Japan	Hiyama	Walleye Pollock *Theragra chalcogramma* (Gadidae)	29

To evaluate the extent of losses from spillovers of adults and larvae, a benchmark was established: if one TURF is large enough to eliminate both types of spillover ($c = m = 0$), no externalities exist, and the Nash equilibrium produces the Maximum Sustainable Yield (MSY). This could represent a fishery where the entire stock (for highly connected resources) or microstock (for species with high levels of self-recruitment such as abalone; [33]) is owned by a cooperative. While such a scenario is likely to be infeasible in many settings, it serves as a useful point of comparison.

In contrast, when TURFs are smaller, owners must account for spillover when choosing harvest, and the resulting Nash equilibrium entails a race to harvest before the resource moves to the other patch. Those equilibrium yields were subtracted from the MSY to calculate the expected losses in yield resulting from different TURF sizes [46]. To separate the effects of larval dispersal and adult movement, two scenarios were examined. In the first scenario spillover is a consequence of adult movement alone by keeping $m > 0$ in the adult stock density function and $c=0$ in the larvae production and dispersion function. In the second scenario spillover is due exclusively to larval dispersal by setting $c > 0$ in the larvae production and dispersion function and $m=0$ in the adult stock density function. Setting c and m to zero in the larvae production/dispersion function and in the adult stock destiny function respectively results in $S_i^t = P(N_i^t + M_i^t)$ and $M_i^t = 0$.

Using this model, three major TURF systems within Chile, México and Japan were analyzed. For each case study data on sizes (alongshore lengths) of the TURFs (Table 1) and the parameters of the species they manage (Table 2) were collected. For Chile, data on TURF size were obtained from SUBPESCA [43]. For Japan, the size of TURFs in Hiyama and home range of walleye pollock were obtained from Uchida & Watanobe [45]. Data on home range of sakuraebi and the size of the fishing grounds in Suruga Bay were calculated from the maps of Uchida & Baba [44]. Data on the size of the Mexican FEDECOOP TURFs were obtained from McCay et al. [22].

Dispersal kernels were created based on the parameters of each species presented in Table 1. The kernels were estimated using the model of Siegel et al. [41] that simulates the trajectories of particles under the different conditions of velocity and turbulence generically characteristic of coastal areas. The result of these simulations is a Gaussian probability function with a standard deviation $\sigma_d = 2.238\sigma_u T_{PLD}^{1/2}$ that depends on the root mean square of the current velocity (σ_u) and the planktonic larval duration (PLD) of the species. The distances that larvae disperse depend on many biological and oceanographic characteristics that are not taken into account in the model. As a result, these simplified kernels tend to overestimate larval dispersion, particularly for species with long PLD [41]. Therefore a highly conservative value for the current velocity of $\sigma_u = 1$ was used. Finally, the fraction of larvae leaving the TURF (*c* in the larvae production and dispersion function) was estimated by integrating the area under the tails of the kernel that disperse a distance greater than half of the TURF length. Fig. 2 shows the levels of spillover resulting from different sizes of TURFs for each species. The proportion of larvae exported in each of the case studies in relation to the rounded average TURF size is presented in Table 3. Adult movement was calculated as the proportion of adults that move outside the patch based on the species home range size relative to the length of the patch, using the model from Kramer and Chapman [19].

Landing statistics and biomass calculations (when available) were used to quantify performance of the TURF systems in each case study. Since biomass calculations are not publicly available for Chilean loco, it was assumed that the assigned TAC [42], which is calculated in monitoring efforts in each TURF [16], represents 25% of the biomass. This represents a conservative calculation since the assigned TAC for TURFs is calculated as 15–25% of the available biomass [16]. The information was gathered from data and figures available in peer reviewed publications and governmental reports [14, 16, 23, 25, 36, 37, 38, 42] using Web Plot Digitizer [34].

3. Results and discussion

The simulations show that the TURF systems fall into three distinct categories: (a) TURFs that are of adequate size to eliminate the expected negative effects of both adult and larval movement, (b) TURFs that are large enough to eliminate the expected negative effects of adult movement, but not the effects of larval dispersal (c) TURFs that are too small to eliminate the expected impacts on yield of both adult and larval movement.

The Mexican North Pacific FEDECOOP TURFs are the only TURFs in the first category with respect to the dispersal capacity of green abalone. Two groups of TURFS – spiny lobster in the FEDECOOP TURFs and the TURFs from the Chilean system – fall into the second category. They are large relative to adult movement but too small to retain most larvae produced inside. Finally, TURFs from Japan fall into

Table 2
Life history parameters corresponding to the species targeted within each of the TURF systems analyzed.

Species	Adult home range (meters)	Inverse life span (years)	Pelagic Larval Duration (PLD; days)	Sources
H. fulgens	13.52	0.025	3.5–9	Tegner & Butler 1985; Hobday et al. 2001; Coates et al. 2013
P. interruptus	100	0.05	210–270	[46]
C. concholepas	13.52	0.1	90	Bigatti et al. 2006; [32]
S. lucens	90,000	0.76	52	[44]; Omori & Gluck 1979
T. chalcogramma	446,000	0.066	108	Cohen et al. 1990; Houde & Cruz 1994; [45]

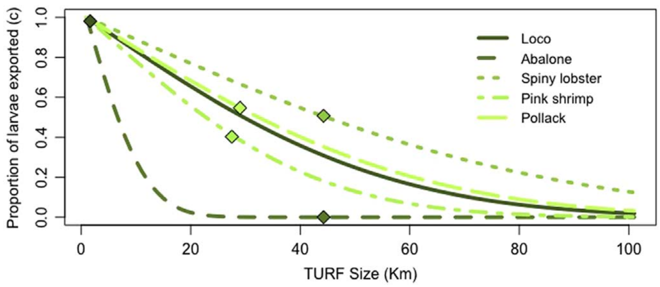

Fig. 2. Proportion of larvae exported for each species if managed using TURFs of 0–100 km of along shore length. Diamonds show the actual level of larval spillover based on the rounded average TURF size of each case study.

Table 3
Proportion of larvae that move outside of the TURF (c) based on the rounded average TURF size of each case study.

Case study	Proportion of larvae exported (c)
Spiny Lobster	0.507
Abalone	0.0000003
Loco	0.981
Pink Shrimp	0.403
Pollock	0.547

the third category, since both the estimated larval dispersal and adult movement are large relative to the size of the TURFs.

These theoretical projections suggest the biomass of abalone should trend upward, but the high levels of expected spillover in the Mexican (for spiny lobster), Japanese and Chilean TURF systems should (a) increase competition among TURFs leading to a race to fish, and (b) compromise biomass and yields.

Fig. 4D shows the landing statistics and biomass calculations for all species of Abalone in the Mexican Pacific, of which green abalone is the most abundant [23]. Although landings statistics show a positive trend on biomass since the creation of the TURFs, a strong recent drop reflects that TURFs have not been as successful as the model suggests [36]. It is important to consider that these species are slow growing and highly susceptible to environmental disturbance and Allee effects [23], therefore the full recovery of the stock will take a long time and/or requires complementary management tools [35].

On the other hand, the model predicts that the expected losses in yield would be roughly 30–80% of maximum sustainable yield (MSY) for the spiny lobster fishery in FEDECOOP TURFs, 80% of MSY for walleye pollock TURFS, 30% of MSY for sakuraebi TURFs, and more than 90% of MSY for most TURFs in the Chilean system (Fig. 3). All these TURF systems are thus too small to eliminate the effects of spillover. This is unsurprising since the sizes of existing TURFs are largely determined by the need to match local social, cultural and geographical conditions to facilitate the development of successful co-management schemes [1, 2, 7, 10, 13, 48]. This typically involves creating areas smaller than those needed to eliminate the effect of spillover [31], which theoretically could lead to a race to fish. Still, although with the available information it is not possible to calculate how far all these systems are from MSY in practice, several lines of evidence suggest that TURFs help avoid both the race to fish and compromised yields in the case studies analyzed. Fig. 4 shows landing statistics for all case studies. Although there are no formal calculations of biomass for the Pink Shrimp stock fishery [44] the fishery shows constant landings since the 1970s (Fig. 4A). According to Uchida and Baba [44] these TURFs have helped achieve within-season price stabilization by spreading harvest over time and reduce gear and vessel congestion, both of which suggest a reduced race to fish. In Chile (Fig. 4E) landings have remained constant after the creation of the first TURFs in 1997, and biomass has increased since TURFs became the only source of legally landed loco in 2001 [42]. Researchers have observed an increased abundance of loco [6,16] and long-term analysis have found that the catch per unit of effort has increased along with the value of the resource [12]. In México (Fig. 4C) the establishment of exclusive rights in 1992 led to an increase in spiny lobster landings and biomass. Furthermore, this fishery was awarded a sustainability certification [21], indicating that yields are likely not compromised to the extent suggested by the model.

One hypothesis to reconcile these mismatches between predictions and practice is that cooperation among TURFs may account for the better than expected performance of these TURF systems. Numerous studies in social-ecological systems have shown that the Nash equilibrium is rarely the observed outcome in social dilemmas, and cooperation has often been used to solve common pool resource problems through coordination, public input provision, information

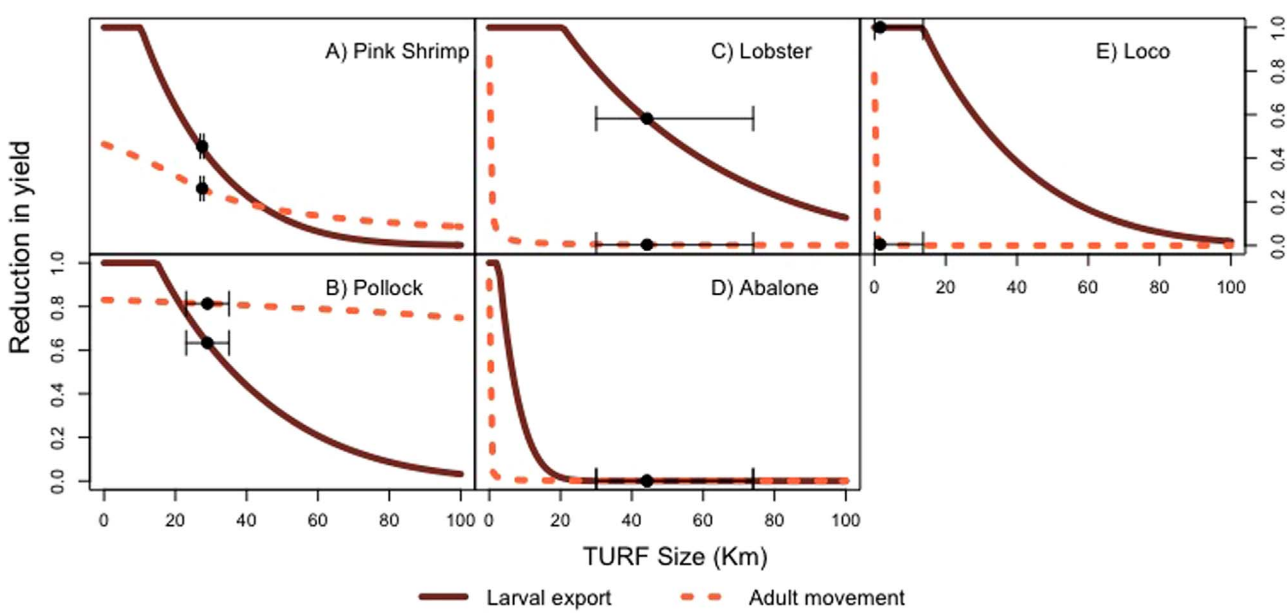

Fig. 3. Effect of spillover on yield. Effects of larval dispersal (solid lines) are separated from the effects of adult movement (dotted lines). Black dots represent the actual average TURF size for each case study. Bars show the range of TURF sizes within each system.

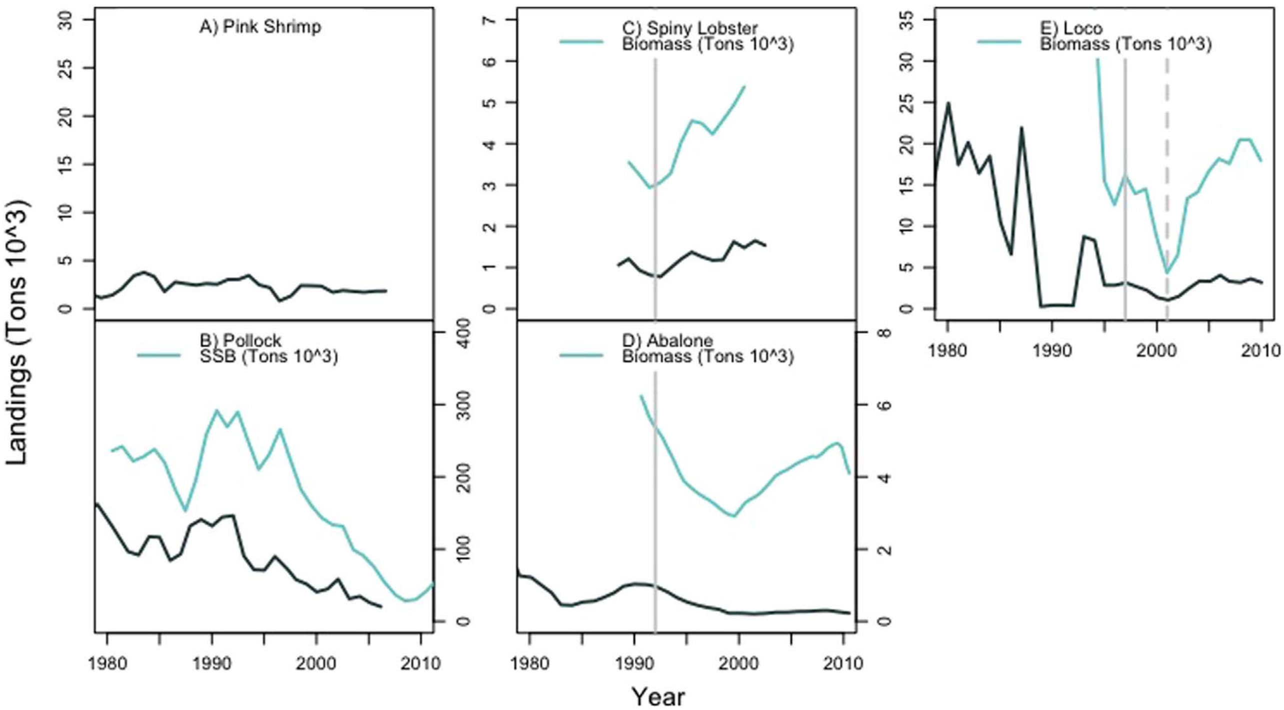

Fig. 4. Historical landings (dark blue lines), stock biomass (light blue lines), and year of legal TURF creation (solid grey vertical lines) for all case studies. Landings and stock biomass measured in thousands of tons. For loco (E) the dashed vertical line indicates when TURFs became the only source of legal landings.

sharing and stewardship [11,27]. Therefore, inter-TURF cooperation could significantly reduce the negative effects of expected spillover from small TURFs.

In particular, unitization or income pooling, where the users of the resources share profits and thus face reduced incentives to take actions that negatively affect the yields of neighboring users, is a well-known solution to spatial externalities [18]. Several authors have described the income pooling systems of the case studies analyzed from México and Japan [18, 38, 44, 47]. The FEDECOOP TURFs depend on a unitization arrangement, since the cooperatives give a portion of their profits to the Federation, and these profits are then returned to the cooperatives in the form of “marketing services, technical expertise for fisheries management, and a venue for collective bargaining” [9,22]. In Suruga Bay the cooperatives have developed an income pooling arrangement that has helped this fishery become one of the most profitable in Japan [38]. Finally, the walleye pollock TURF's cooperative efforts have resulted in the design of a rotation system to reduce the inequalities in access to the best fishing grounds [47].

The absence of cooperation in the theoretical TURF model limits our ability to predict when such successful cooperation will arise and when it will not. For example, in Suruga Bay the benefits of cooperation for enhanced outcomes may be maximized, since movement of the resource is only between cooperatives that fish within the bay. The pelagic shrimp do not appreciably move beyond the collection of cooperating TURFS [44]. Conversely, the benefits from cooperation are more limited for the pollock cooperatives. Although local captures show a stable trend, empirical evidence indicates the high mobility of pollock is diluting the efforts of the Hiyama region cooperatives to improve the conditions of the fishery, and the northern Japan Sea walleye pollock stock is in decline (Fig. 3B; [45]).

In the case of Chile, the simulations show that individual TURFs are facing a high level of larval spillover. It is important to note that these results arise from applying a simple larval dispersal model that does not take into consideration processes that could cause larval retention in coastal areas, which have been shown to exist in the Chilean coast and affect loco's larval dispersal [24,32]. However, use of low current velocities in our simulations should limit over-estimation of larval dispersal capacity. Previously developed larval dispersal models that take into consideration complex oceanographic processes in the Chilean coast have calculated a mean dispersal distance of loco larvae between 198.77 and 262.65 km [15]. The model applied here calculates that only 2% of larvae are exported to a 100 km distance (Fig. 2). Our model is thus highly conservative in terms of larval dispersal distance.

In Chile, although some cooperation among TURFs exists [7], it is unlikely that it will solve the spillover problem for two main reasons. First, unlike the Japanese TURFs, where adult movement makes the migration patterns more evident, in Chile the spillover is mainly due to larval export. The patterns of dispersal are hard to characterize, complicating the identification of other fishing groups with whom cooperation should be developed in order to solve the spillover problem. Second, unlike the FEDECOOP cooperatives, most of the Chilean TURFs are surrounded by open access areas, which inhibits cooperation, since the payoffs are diminished by activities in the outside areas. Although fishing loco outside TURFs is prohibited, poaching is still a common activity in open access areas [3,26]. Furthermore, these two conditions diminish the possibilities of face-to-face communication among TURFs owners that depend on the same resources, which is essential for the development of cooperation [27].

Another possible explanation for the disparities between the expected negative effects of spillover and the observed constant harvests in the Chilean system is the presence of catch-limits. In Chile fishermen have to constrain catches to a TAC mandated by the federal government. This type of measure could maintain harvests at constant levels when designed according to sound scientific information and appropriately enforced [4]. However, this regulation does not seem to be the central driver for sustainable practices among TURF owners, since their landings tend to be consistently far below this limit [6], which indicates the presence of other incentives for conservative harvests.

Therefore, although cooperation and catch limits may be resolving many problems associated with spillover in several settings, the success of TURFs in the face of extensive larval dispersal into areas of open access fisheries, such as the case studies from Chile, remains unresolved. Two hypothetical explanations that warrant further explanation for why TURFs with high levels of larval spillover might not overexploit their resources are proposed. First, fishermen may not be aware of the effects of larval movement. Unlike the observable nature of adult movement, larvae are microscopic and their fate may be poorly understood by fishermen. A lack of knowledge about larval dispersal may reduce the resulting incentives for overharvesting since, by ignoring the connection with outside areas, fishermen might not feel the need to rush for fish. Alternatively, the effects of larval spillover may differ from adult spillover due to the delayed consequences of larval dispersal. Since larval export only affects future yields, and the delay can be quite substantial for slowly maturing species, the perceived costs may be greatly discounted relative to the immediate costs of adult dispersal. Since the model explored here does not include age structure in the fish population, the impacts of larval dispersal have no lag and therefore may be greatly overestimated.

4. Conclusion

The expected effects of fish dispersal capacity on yields suggest that the analyzed TURFs are small relative to both adult and larval movement. In some cases, this spillover and its consequent incentives for fishermen behavior may be driving overharvesting. However, in several other settings small TURFs may still be successful because of inter-TURF cooperation. Further, imperfect observability and delayed effects of larval dispersal may reduce incentives fishers have to overharvest. Ignoring such complications can lead to a poor understanding of these systems and therefore lead to inefficient designs. As such, further development and extension of these models is warranted so that they can play a more important and beneficial role in guiding decisions on marine spatial planning. In particular, an enhanced version of the model analyzed could be highly informative in cases where the design of TURFs is constrained by social or natural boundaries. Such models could help decide where complementary tools to solve the spillover problem in spatial property rights should be promoted.

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