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REVIEW

# Informing the design of territorial use rights in fisheries from marine protected area theory

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ABSTRACT: Territorial use rights in fisheries (TURFs) can be an effective tool for the management of coastal resources, and interest in their use is increasing around the world. However, there is little guidance on how to design them. Fortunately, other marine spatial tools, such as marine protected areas (MPAs), have already addressed questions similar to those now central to successful TURF design. We propose that well-established lessons from MPA design should provide a strong basis for the development of design criteria for TURFs. In this paper, we review the MPA literature to inform the design of TURFs based on the similarities and differences of these 2 marine spatial management tools. We found that TURF design can obtain important lessons from MPA theory, for example on how to diminish the effects of environmental and human disturbance. In particular, the nascent idea of creating TURF networks can benefit significantly from the literature on MPA networks.

KEY WORDS: TURFs · Marine tenure · Property rights · Small-scale fisheries · Artisanal fisheries · Co-management · Social–ecological systems · Marine conservation



## INTRODUCTION

As coastal human populations continue to increase, demand for and pressure on coastal fisheries are increasing as well. In particular, where fisheries are poorly managed, increased fishing pressure has led to overfishing and even stock collapse (Pauly et al. 2005). To help mitigate this situation, many fisheries managers argue for generating incentives for sustainable harvest by giving fishermen a guaranteed stake in the resource (Costello et al. 2008). At local scales, a common tool for this approach are territorial use rights in fisheries (TURFs). TURFs are a form of catch share in which the access rights are defined spatially. Similar to the influence of property rights on other forms of resource extraction (Arnason 1996), TURFs can provide incentives for fishermen to extract resources sustainably by giving fishermen exclusive access to a particular location, which is intended to represent a portion of the total catch. As with other forms of catch shares, as the stock increases, total catch, and thus the value of the TURF, increases (Smith & Panayotou 1984, Cancino et al. 2007, Costello & Kaffine 2010, Wilen et al. 2012).

Furthermore, TURFs can enable the conditions for successful co-management arrangements (Pomeroy & Berkes 1997, Gelcich et al. 2010, Sanchirico et al. 2010, Gutiérrez et al. 2011). Although TURFs have existed for centuries, the growing evidence of their success (Defeo & Castilla 2005, Uchida & Baba 2008, Uchida & Watanobe 2008, Gelcich et al. 2010, McCay et al. 2014) has generated a renewed interest in their establishment in new places around the world. However, until now, TURF design has largely been guided

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by the location and shape of traditional fishing grounds (Ponce-Taylor et al. 2006, Shester 2008, Wilen et al. 2012, Bonzon et al. 2013), with little foundation in either social or ecological research. This approach is unlikely to produce favorable social and ecological outcomes, particularly in the absence of long-standing marine tenure that could provide references for TURF design based on traditional ecological knowledge. Therefore, the creation of scientifically based guidelines, which allow the design of new successful TURF systems, is needed.

A key challenge to the development of these guidelines is that most existent TURF systems manage artisanal fisheries, which are predominantly data-limited (Jacquet & Pauly 2008). Thus, TURF research has had to rely on the few data-rich case studies (such as the TURFs in Mexico, Chile and Japan) for information on performance. As such, there is relatively little empirical information from which to base (or validate) design principles, particularly in social and ecological settings that differ from those few well-studied TURF systems. However, TURFs should perform in ways very similar to marine protected areas (MPAs), as both are spatial enclosures designed to manage marine resources within their boundaries but subject to (and influencing) processes outside their boundaries. Although TURFs and MPAs tend to be designed with different objectives (extraction vs. conservation), the success of both depends heavily on how well their design fits the oceanographic, biological and social conditions of a selected location (Gaines et al. 2010b, Poon & Bonzon 2013, Afflerbach et al. 2014). Our premise here is that lessons from MPA design theory should provide substantial fodder for the development of design criteria for TURFs. Indeed, many questions currently being asked about TURFs — e.g. what is the appropriate scale of TURFs and TURF systems? (Holland 2004, Wilen et al. 2012) — have also been an important subject of MPA research (Gaines et al. 2003, Gerber et al. 2003). Although TURF research has already been influenced by MPA literature, particularly in existing theoretical models (e.g. Gerber et al. 2003, Costello & Kaffine 2010, White & Costello 2011), a formal review that systematically facilitates this cross learning exercise does not exist.

Here we critically review the MPA literature from the perspective of TURF design, using similarities and differences to determine which guidelines directly apply to both cases and which need to be adapted for TURFs. We focus in particular on the aspects of the theory of MPA design that relate to fisheries objectives. In the following sections, we briefly review the main criteria currently used to inform decisions about the size, location and shape of single MPAs as well as the size, location and spacing of MPA networks. We then discuss the applicability of these criteria to TURFs to offer a theory of TURF design. We found that MPA literature has particularly important lessons in relation to the maintenance of healthy fish populations through connectivity, as well as for the reduction of the effects of disturbance and the inclusion of critical habitats, particularly for TURF networks.

## METHODS

We performed a systematic review following the 'preferred reporting items for systematic reviews and metaanalyses' (PRISMA) protocol, whose objective is to address the suboptimal reporting of reviews through a set of guidelines of the necessary information to be reported (Moher et al. 2009).

### MPA literature

Our aim was not to review the thousands of empirical studies on MPAs, but instead to find the criteria that experts agree are most important in MPA design. Thus, our search focused on MPA theory papers that provide a synthesis of design guidelines. To do this, we looked for review papers only, from any year, using the Web of Science platform. Only papers in English were considered.

We focused on review papers that explicitly describe criteria for the design of MPAs. We searched using the keywords 'Marine Reserve*' or 'Marine Protected Area*'. We identified 105 papers through the data search and 7 more through snowball searches (see Supplement 1 at www.int-res.com/articles/suppl/m596p247_supp.pdf). We eliminated those papers that did not discuss design criteria and those that did not clearly state design recommendations. For example, one study evaluated 'the consequences of MPA implementation on the ability to monitor and assess fishery resources consistent with existing methods and legislative mandates' (Field et al. 2006, p. 284). This resulted in 28 articles to be reviewed in detail (Supplement 3). To build Tables 3 & 4, we eliminated reviews whose main objective was not to provide general guidelines for MPA design. For example, Dunne et al. (2014) discussed the legal and livelihood consequences of failing to engage stakeholders in the Island of the Chagos Marine Protected Area, but did not provide clear design recommendations. Ultimately, a total of 17 studies were included in Tables 3 & 4 (see Table 5).

### TURF literature

Because fewer papers have addressed TURF design compared to MPAs, we ran a systematic search for all types of documents (not only literature reviews) with the keywords 'Territorial Use Rights', 'Spatial Property Rights' or 'Marine Tenure'. We identified 139 initial papers and 5 more through a snowball approach (Supplement 2). We eliminated studies that did not focus on TURFs (e.g. Krausse 1995, Allison et al. 2001) or did not provide guidelines for TURF design (e.g. Siar et al. 1992, Blanco et al. 2017), leaving 36 papers to review in detail (Supplement 4). Of those, 28 papers discussed the design guidelines found in MPA literature and were used as references for Tables 3 & 4 (see Table 5).

### Synthesis

We synthesized the MPA design literature and distilled outputs into 'choice variables' and 'design criteria' (Fig. 1). Choice variables are the characteristics that determine different MPA designs and include size, location and shape of single MPAs as well as size, location and spacing of MPA networks. By design criteria, we refer to the social and ecological conditions that drive the selection of different configurations of the choice variables. As this literature has been reviewed extensively already (e.g. Airame et al. 2003, Roberts et al. 2003, Gaines et al. 2010a,b, Green et al. 2014), we only briefly summarize social and ecological design criteria for MPAs identified through our literature review (Tables 1 & 2).

Throughout the paper, we use the concept of the 'conservation MPA' (CMPA) for all MPAs designed with the objective of conserving habitats contained within (even if fishing activities are practiced within them). By 'fisheries MPA' (FMPA), we refer to areas designed to enhance fisheries outside the marine reserve. We use MPAs to refer to both CMPAs and FMPAs collectively.

We analyzed if and how the established MPA criteria have been addressed in TURF literature, and whether key gaps (and opportunities for learning) exist. When no references in TURF literature were found, we developed our own recommendations based on lessons gleaned from the MPA literature (shown in red in Tables 3 & 4). In the 'Results', we describe how each of the criteria presented in Tables 1 & 2 can be used to decide the appropriate size, location and shape of individual TURFs, as well as the size, location and spacing of TURF networks (choice variables), building on established criteria for MPA design. We briefly summarize the overall findings of existent TURF literature for those criteria that have been discussed extensively in MPA research. We provide an extended discussion on those criteria from the MPA literature that have not been directly addressed in the TURF literature.

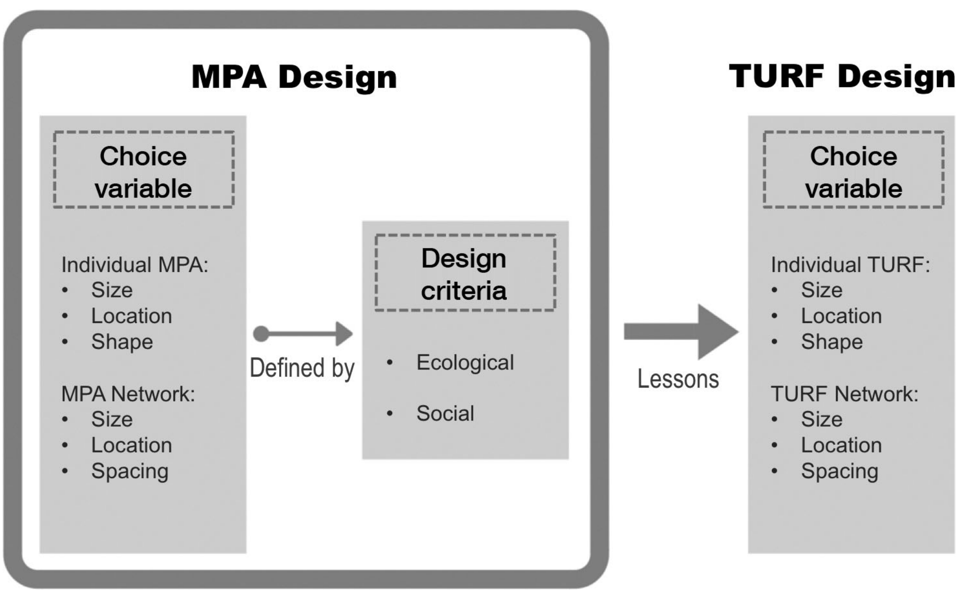


Fig. 1. General structure for how marine protected area (MPA) design lessons were applied to territorial use rights in fisheries (TURF) design. We synthesized the MPA design guidelines into 'choice variables' and 'design criteria.' This framework is applied to develop recommendations for TURF design

## LESSONS FOR INDIVIDUAL TURF DESIGN

### Size

Although empirical evidence indicates that MPAs of all sizes can meet conservation and fisheries objectives, their effectiveness at achieving stated goals is highly contingent on how ambitious the goals are and how big the MPAs are (Halpern 2003, Claudet et al. 2008, Lee et al. 2015). The appropriate size of an MPA for any given location and objective depends on the size of critical habitats, level of existing disturbance within the boundaries of the proposed MPA, expected level of spillover, fishing pressure outside the MPA, feasibility of management, level of sociocultural heterogeneity and the need to increase sustainable fisheries yields (Airame et al. 2003, Botsford et al. 2003, Halpern 2003, Halpern & Warner 2003,

Table 1. Marine protected area (MPA) ecological design criteria

| Design criteria | Description |
|---|---|
| Biogeographic representation | The location and arrangement of an MPA and/or an MPA network should be designed to include areas within all biogeographic regions. This allows the protection of a wide range of habitats and species as well as protecting transition zones between biogeographic regions (Airame et al. 2003, Roberts et al. 2003) |
| Critical habitats | Critical habitats are sites that play an important role in the life history of a species. The protection of critical habitats is necessary for the maintenance of fish populations within MPAs (Botsford et al. 2003, Roberts et al. 2003, Almany et al. 2009, Gaines et al. 2010b) |
| Disturbance | Disturbance events from anthropogenic and/or environmental sources can have a large impact on MPA performance, and they can occur in a great variety of spatial and temporal scales. Infrequent and small-scale threats can sometimes be mitigated. However, areas with frequent, large catastrophes are not good candidates for MPA placing. To obtain the best results from protection efforts, MPAs should be located in areas that are less affected by human and environmental impacts (Airame et al. 2003, Botsford et al. 2003, Roberts et al. 2003, Allison & Hobbs 2004) |
| Exploitable species | MPA location should consider the distribution of exploitable species to diminish the damaging effects of fisheries on marine populations. Empirical evidence (Halpern 2003) and theory (Gerber et al. 2003) suggest that selecting MPA sites based on their historical importance to fisheries, even when they are no longer active fishing sites, can help recover over-exploited species (Roberts et al. 2003) |
| Habitat gradient | To protect species that perform ontogenic migrations, MPAs should include habitat gradients by extending from the intertidal zone to offshore in order include a variety of depths and transition zones (Roberts et al. 2003, CDFG 2008, IUCN-WCPA 2008) |
| Habitat representation and heterogeneity | Within each biogeographic region, MPAs should include all habitats (Airame et al. 2003). Habitat representation allows the inclusion of a wide range of species in the protection scheme as well as the protection of the resources needed for the development of the organisms contained within it (Roberts et al. 2003, IUCN-WCPA 2008, Gaines et al. 2010b, Green et al. 2014). The definition of habitats can be broad or fine scale, and some authors have even suggested that sub-habitats should be used to design the MPA networks (Parnell et al. 2006) |
| Replication | Inclusion of replicates of each habitat provides 'stepping-stones' that allow the dispersal of larvae between areas and therefore connectivity between populations (Palumbi 2004). Furthermore, replication ensures that risk is shared in space in the face of disasters and other severe disturbances (Roberts et al. 2003, IUCN-WCPA 2008, Gaines et al. 2010b, Green et al. 2014) |
| Resilient areas | Ecosystem resilience is the 'ability of an ecosystem to maintain key functions and processes in the face of stresses or pressures, either by resisting or adapting to change' (McLeod et al. 2009, p. 362). MPAs should be established in places with high resilience, particularly in the face of climate change, since they will have a stronger capacity to cope with long-term changes (IUCN-WCPA 2008). Areas that are more resilient to the effects of climate change include areas that have suffered past environmental changes, areas where temperature and ocean chemistry are continuously changing and areas where sea level can rise without anthropogenic obstruction (Green et al. 2014) |
| Spillover | Adult and larval spillover from fisheries MPAs (FMPAs) is necessary to enhance fishing yields in the surrounding areas. If the objective is to increase fisheries yields outside of the MPA, MPAs should be small and separated by larger distances to allow fishing activities. However, if the objective is to conserve marine resources, large MPAs that are closer to each other are more appropriate (Airame et al. 2003, Halpern & Warner 2003, Gaines et al. 2010b, Green et al. 2014) |
| Connectivity | Facilitating connectivity for both FMPAs and conservation MPAs promotes the persistence of fish populations and their recovery after disturbance (Roberts et al. 2003, Green et al. 2014) |
| Vulnerable species and habitats | The presence of vulnerable species and habitats is a priority when selecting the location of both MPA types. Vulnerable habitats include those particularly affected by disturbance, habitats with low resilience (i.e. coral reefs and salt marshes) as well as habitats that are regionally rare or threatened (Roberts et al. 2003). Vulnerable species include species or populations with narrow distributions, restricted ranges or that are endemic (Botsford et al. 2003, Roberts et al. 2003) |

Table 2. Marine protected area (MPA) social design criteria

| Design criteria | Definition |
|---|---|
| Conflicts with human activities | Because fishing MPAs (FMPAs) and conservation MPAs (CMPAs) restrict use of the marine resources within their boundaries, their creation inevitably leads to conflicts with human activities. When the degree of conflict is high, MPA implementation may be met with low levels of compliance (Roberts et al. 2003, Sciberras et al. 2013). Therefore, MPA design should prevent current and foreseeable types of conflict that their establishment will cause to the surrounding resource users and local communities (CDFG 2008) |
| Ecosystem services | All ecosystems provide services for human populations. In ocean systems, food provision through fishing is perhaps the most evident. However, healthy ecosystems can also provide other services such as coastal protection, water filtration and recreation. MPAs placed in key areas for ecosystem services can help maintain ecosystem health and maximize the benefits to humans (Roberts et al. 2003) |
| Fisheries regulations outside the MPA | Optimal design of MPAs depends on the presence and extent of management plans and fisheries regulations outside the reserve. Fisheries regulations refer to the application of a broad range of fisheries management tools from gear restrictions to market-based incentives. Their level of efficiency influences the capacity of an MPA to reach both conservation and fisheries goals (Halpern 2003, Roberts et al. 2003, Holland 2004, CDFG 2008, IUCN-WCPA 2008, Sciberras et al. 2013, Erler et al. 2015) |
| Management feasibility | Management of an MPA implies the protection of its borders as well as the regulation of fishing activities inside when permitted. Depending on the degree of enforcement required, this criterion can greatly influence the appropriate size and location of MPAs (Airame et al. 2003, CDFG 2008) |
| Socio-cultural heterogeneity | FMPAs and CMPAs that accommodate the needs of a wide array of user groups achieve relatively higher levels of compliance and therefore are more likely to be successful (Roberts et al. 2003, Sciberras et al. 2013) |
| Enforcement and transportation costs | To reduce the costs of enforcement and transportation, MPAs should be close to a port. In particular, for FMPAs, a location close to port is important to ensure cheap access for fishermen to the reserve's edge, which will likely have the highest fish density (Gaines et al. 2010a) |
| Traditional use | When deciding the appropriate design of an MPA, it is important to consider the traditional use of the area including heritage value and recreational value (Roberts et al. 2003) |
| Fishing pressure | However, in areas where the fishing pressure is too high it may be best to choose a different location since the recovery of the site could incur high social costs (Roberts et al. 2003). Large marine reserves help to reduce the effect of high levels of fishing pressure on marine populations; thus, when the level of fishing pressure is high, a network of both small and large marine reserves is recommended (Green et al. 2015) |
| Sustainable fisheries yields | Marine reserves can be designed with the objective of increasing sustainable fisheries yields outside their boundaries. To achieve this objective, FMPAs need to be designed in a way in which the level of spillover is maximized. To do so, building networks of small FMPAs is recommended (Gaines et al. 2010b) |
| Clear boundaries | Shapes that allow a clear differentiation of the reserve boundaries can facilitate enforcement and compliance. Preferably they should be clearly marked by using references on the coastline that are easy to recognize. Straight lines are recommended to facilitate enforcement (CDFG 2008, McLeod et al. 2009) |

Roberts et al. 2003, CDFG 2008, Almany et al. 2009, Gaines et al. 2010b, Green et al. 2014) (Table 3).

Of these criteria, the effects of spillover, the level of fishing pressure outside, the level of socio-cultural heterogeneity and sustainable fisheries yields improvement have received the most attention in TURF literature (e.g. Christy 1982, White & Costello 2011, Poon & Bonzon 2013, Aceves-Bueno et al. 2017). For successful individual TURFs, spillover to outside areas should be reduced as much as possible. With larger TURF sizes, the level of spillover can be minimized, which strengthens exclusivity over fishing resources and creates the necessary conditions to increase sustainable fisheries yields. In this sense, TURF size guidelines are similar to those of CMPAs and opposite from those of FMPAs (Table 3). These conditions create the right incentives for the owner to manage the TURF in a sustainable manner, particularly in the presence of strong fishing pressure (Sanchirico et al. 2010, White & Costello 2011). However, small TURFs can perform well in the presence of inter-TURF cooperation (Aceves-Bueno et al. 2017).

In terms of socio-cultural heterogeneity, existing guidelines indicate that large TURFs do not provide enough flexibility to accommodate the needs of a diverse group of users (Cancino 2007). In a setting with high social heterogeneity, a single large TURF could lead to conflicts among users. Thus, to reduce conflict and improve the performance of TURFs, TURFs should be sized with respect to 'social functional units' facilitating coordination and allowing cooperation among groups (Poon & Bonzon 2013).

Table 3. Criteria for the design of individual conservation marine protected areas (CMPAs) and fisheries MPAs (FMPAs) and their application to the design of individual territorial use rights in fisheries (TURFs; A: avoid; I: include). Arrows indicate the direction of the choice variable: ↑ = increase ↓ = reduce. Red shading highlights the design recommendations for which no references were found in the TURF literature and for which we developed our own recommendations based on the MPA literature. TURF references are listed in Table 5

| Choice variable | Design criteria | | Desired outcome (design criteria direction) CMPA | FMPA | TURF | Design recommendation (choice variable direction) CMPA | FMPA | TURF | MPA reference(s) | TURF reference(s) |
|---|---|---|---|---|---|---|---|---|---|---|
| Size | Ecological | Critical habitats | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | 2,4,7,29,31 | |
| | | Disturbance | ↓ | ↓ | ↓ | ↑ | ↑ | ↑ | 22,30,40 | |
| | | Spillover | ↓ | ↑ | ↓ | ↑ | ↓ | ↑ | 4,21,28,29,30,31 | 1,9,11,13,16,36,38,41,44,45 |
| | Social | Management feasibility | ↑ | ↑ | ↑ | ↑ | ↑ | ↑↓ | 4,8,18 | 11,33 |
| | | Sustainable fisheries yields | – | ↑ | ↑ | – | ↓ | ↑ | 22 | 1 |
| | | Fishing pressure | ↓ | ↓ | ↓ | ↑ | ↑ | ↑↓ | 30 | 27,38 |
| | | Socio-cultural heterogeneity | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | 4,40 | 5,9,11,13,14,23,24,38,45 |
| Location | Ecological | Vulnerable species and habitats | ↑ | ↑ | ↑ | I | I | I | 4,7,40 | |
| | | Exploitable species | ↑ | ↑ | ↑ | I | I | I | 40 | 17,27,35 |
| | | Disturbance | ↓ | ↓ | ↓ | A | A | A | 4,7,40 | |
| | | Habitat gradient | ↑ | ↑ | ↑ | I | I | I | 8,32,40 | |
| | | Resilient areas | ↑ | ↑ | ↑ | I | I | I | 28,32 | |
| | Social | Conflicts with human activities | ↓ | ↓ | ↓ | A | A | A | 8,18 | 38 |
| | | Ecosystem services | ↑ | ↑ | ↑ | I | I | I | 40 | 37 |
| | | Traditional use | I | I | I | I | I | I | 40 | 5,11,12,13,14,15,16,20,23, 24,26,27,38,39,42,43,45 |
| | | High transportation and enforcement costs | ↓ | ↓ | ↓ | A | A | A | 18,22 | 3,11,25,26,33,36,45 |
| Shape | Social | Clear boundaries | ↑ | ↑ | ↑ | I | I | I | 8,34 | 3,11,13,33,38 |

Although management feasibility has been addressed in TURF literature (e.g. Basurto et al. 2013, McCay et al. 2014), important lessons can be drawn from MPA research. The implications of management feasibility for TURFs are very similar to those for MPAs. In general, in order to facilitate management, MPA design should balance the need to monitor activities at MPA boundaries and within them (Roberts et al. 2003, CDFG 2008, IUCN-WCPA 2008). Small FMPAs and CMPAs typically require greater enforcement effort per unit area due to larger edge to area ratios. Larger MPAs reduce these ratios, thus allowing enforcement efforts to be concentrated, which facilitates monitoring and reduces costs (Airame et al. 2003, CDFG 2008). As with MPAs, larger sizes in TURFs facilitate protection since the edge to area ratio is smaller, creating a shorter border per unit area to enforce. However, with increased size, a larger enforcement effort inside TURFs and MPAs could be required. Particularly, larger TURFs and fishing CMPAs will generally include more fishermen, which could increase the costs of coordinating fishing activities inside their boundaries (Panayotou 1984, Holland 2004). Thus, in terms TURF size, the need for spillover reduction acts as an opposing force (pushing for larger sizes) to the need for social conflict reduction and strong coordination within the extractive area (pushing for smaller sizes) (Table 2). The effect of fishermen group size (number of fishermen) on TURF success is unclear. Although one would expect that a lower number of users would be most efficient (e.g. reduced enforcement and coordination costs), the membership to size ratio in existing successful TURF systems, such as in Baja California and Chile, varies greatly, and there are successful cooperative systems around the world with both large and small memberships (Cancino et al. 2007, Deacon 2012, McCay et al. 2014). As a consequence of these dynamics, there is no agreement among scholars regarding the most appropriate TURF size. As such, decisions regarding TURF size will require consideration of local context and factors. MPA research provides important lessons

Table 4. Criteria for the design of marine protected area (MPA) networks and their application to the design of individual territorial use rights in fisheries (TURFs; I: include, NR: not relevant). Arrows indicate the direction of the choice variable: ↑ = increase ↓ = reduce. Red shading highlights the design recommendations for which no references were found in the TURF literature and for which we developed our own recommendations based on the MPA literature. TURF references are listed in Table 5

| Choice variable | Design criteria | | Desired outcome (design criteria direction) MPA network | TURF network | Design recommendation (choice variable direction) MPA network | TURF network | MPA references |
|---|---|---|---|---|---|---|---|
| Size | Ecological | Disturbance | ↓ | ↓ | ↑ | ↑ | 19, 28, 34 |
| | | Spillover | ↑ | ↑ | ↑ | ↑ | 19, 28, 34 |
| | Social | Fishing pressure in the management area | ↓ | ↓ | ↑ | ↑ | 19, 28, 34 |
| Location | Ecological | Biogeographic representation | ↑ | NR | I | NR | 4, 34, 40 |
| | | Heterogeneity (representation) | ↑ | ↑ | I | I | 4, 6, 10, 28, 32, 34 |
| | | Replication | ↑ | ↑ | I | I | 6, 32, 34, 40 |
| Spacing | Ecological | Connectivity between areas | ↑ | ↑ | ↓ | ↑↓ | 29, 34, 40 |
| | | Disturbance | ↓ | ↓ | ↑ | ↑ | 28, 34, 40 |
| | | Spillover to fisheries outside | ↑↓ | ↓ | ↑↓ | ↓ | 4, 28, 30 |

regarding the appropriate size of TURFs from an ecological standpoint, but the social aspects of this design criterion remain fertile ground for future research.

Direct discussion of the importance of critical habitats in TURF size selection does not currently exist, although mention has been made of the importance of including spawning grounds, nursery habitats, migratory routes and larval sources (Holland 2004, Poon & Bonzon 2013). Thus, MPA literature can provide important lessons in this regard. Maintaining healthy critical habitats can be particularly important for TURFs with limited or irregular recruitment. For example, by giving a TURF owner the capacity to protect source areas of their target species, the uncertainty related to recruitment can be reduced along with the propensity for competitive behavior among fishermen (i.e. the race to fish), particularly for species with modest to high levels of local recruit-

Table 5. References used in Tables 3 & 4. TURF: territorial use rights in fisheries; MPA: marine protected area

| Reference number | Reference | Subject | Reference number | Reference | Subject |
|---|---|---|---|---|---|
| 1 | Aceves-Bueno et al. (2017) | TURF | 24 | Gelcich et al. (2008a) | TURF |
| 2 | Almany et al. (2009) | MPA | 25 | Gelcich et al. (2017) | TURF |
| 3 | Atapattu (1987) | TURF | 26 | Gelcich et al. (2010) | TURF |
| 4 | Banks & Skilleter (2010) | MPA | 27 | González et al. (2006) | TURF |
| 5 | Berque & Matsuda (2013) | TURF | 28 | Green et al. (2014) | MPA |
| 6 | Botsford et al. (2014) | MPA | 29 | Green et al. (2015) | MPA |
| 7 | Botsford et al. (2003) | MPA | 30 | Halpern & Warner (2003) | MPA |
| 8 | CDFG (2008) | MPA | 31 | Hyrenbach et al. (2000) | MPA |
| 9 | Cancino et al. (2007) | TURF | 32 | IUCN-WCPA (2008) | MPA |
| 10 | Carr et al. (2003) | MPA | 33 | McCay et al. (2014) | TURF |
| 11 | Castilla & Defeo (2001) | TURF | 34 | McLeod et al. (2009) | MPA |
| 12 | Chen (2012) | TURF | 35 | Nomura et al. (2017) | TURF |
| 13 | Christy (1982) | TURF | 36 | Oyanedel et al. (2016) | TURF |
| 14 | Cinner (2005) | TURF | 37 | Ponce-Taylor et al. (2006) | TURF |
| 15 | Coulthard (2011) | TURF | 38 | Poon & Bonzon (2013) | TURF |
| 16 | Criddle et al. (2001) | TURF | 39 | Rivera et al. (2017) | TURF |
| 17 | Dahl (1988) | TURF | 40 | Roberts et al. (2003) | MPA |
| 18 | Francour et al. (2001) | MPA | 41 | Sanchirico et al. (2006) | TURF |
| 19 | Friedlander et al. (2003) | MPA | 42 | Steneck et al. (2017) | TURF |
| 20 | Fujita et al. (2017) | TURF | 43 | Uchida (2017) | TURF |
| 21 | Gaines et al. (2010a) | MPA | 44 | White & Costello (2011) | TURF |
| 22 | Gaines et al. (2010b) | MPA | 45 | Wilen et al. (2012) | TURF |
| 23 | Gelcich et al. (2005) | TURF | | | |

ment. MPA theory has shown that large areas are more likely to contain a bigger portion of critical habitats and therefore ensure the maintenance of healthy populations (Botsford et al. 2003, Almany et al. 2009); similar guidelines make sense for TURFs.

Lastly, we found no guidance on the role of disturbance in deciding optimal TURF size. Large MPAs provide increased protection against acute environmental and anthropogenic disturbance, as well as long-term disturbances such as climate change; having a relatively larger proportion of the fish population under protection reduces its chances of being wiped out by disturbance (Airame et al. 2003, Halpern 2003, Roberts et al. 2003, Gaines et al. 2010b, Green et al. 2014). Similarly, the effect of disturbance on the performance of TURFs depends on how much the scale of disturbance matches the size of the TURF. When TURFs are in place, fishermen's activities are restricted to a determined geographic range. If the effect of disturbance is as large or larger than the TURF, fishermen will have little capacity to reduce its effects on the targeted resource. Therefore, as with MPAs (Meyer et al. 2007, Green et al. 2014), larger TURFs should help mitigate the effects of disturbance.

## Site selection

Criteria for choosing MPA locations include ecological variables, such as the location of vulnerable species and habitats, distribution of exploitable species, strength of human and environmental disturbance and resilience of the location to those disturbances; and social variables, such as the presence of species providing ecosystem services, conflicts with human activities, the area's traditional human use and transportation and enforcement costs (Airame et al. 2003, Botsford et al. 2003) (Table 3). We found that only conflicts with human activities, transportation and enforcement costs, traditional use of the area and the distribution of exploitable species are currently considered in TURF design research.

Because the main objective of TURFs is to enhance fisheries within their boundaries, the presence of exploitable species is the most important criterion for site selection and is a topic addressed in detail in TURF literature. Several lessons emerge from that literature. First, when local communities target more than one species, TURFs should be located based on the distribution of the most important commercial species (Poon & Bonzon 2013). Second, when target species are scarce, TURFs will need to be delineated carefully to include those species to help in their recovery (Dahl 1988). Understandably, most TURFs are currently located in active fishing grounds, yet TURFs could be helpful in the recovery of historical fishing grounds. For example, in Chile, where some TURFs were located in historically important fishing grounds that were overharvested, 25% of TURFs reported no landings during the first year but only 12% during the second year, which led to significant increases of stock density (Wilen et al. 2012). However, MPA research shows that the intensity of past extractive activities can affect the capacity to recover targeted populations (Tegner 1993, Kaplan et al. 2009, Sciberras et al. 2013). Thus, analyzing the recovery potential of the fishery (through management strategy evaluations, MSEs) is critical to avoid false expectations and prevent potential conflicts between the government and future TURF users. Lastly, as with MPAs, TURFs are more successful for sedentary species (Defeo & Castilla 2005, Cancino et al. 2007, Wilen et al. 2012). However, in Japan, some TURFs successfully manage highly mobile species through the development of inter-TURF cooperation. For example, the TURFs that harvest sakura-ebi shrimp *Sergia lucens* in Suruga Bay have developed a profit-sharing system that has maintained the economic value and health of the targeted resource (Cancino et al. 2007, Wilen et al. 2012).

In TURFs, social conflicts can originate from assigning exclusive access rights to a group of fishermen, which in turn may restrict the capacity of others to perform important cultural and economic activities within TURF boundaries. Thus, accounting for different sources of income and cultural traditions in local communities when designing TURFs is important to reduce the chance of TURF failure (Dahl 1988, Defeo & Castilla 2005, Aswani et al. 2007, Aburto et al. 2013, Yates & Schoeman 2015). Clearly identifying 'social functional units' in the region, and using them as a reference for the location of each individual TURF, can facilitate such accounting. Preferably each TURF should be assigned to one social functional unit in each TURF, since groups of people with strong social bonds can have a greater capacity to organize and sustainably manage the area assigned to them (Poon & Bonzon 2013).

The costs of managing and enforcing a TURF should be lower than the benefits of the harvests (Atapattu 1985, Basurto 2005), particularly considering that most TURF owners pay governmental fees in addition to harvest costs (Gelcich et al. 2010, McCay et al. 2014, Davis et al. 2015). Although recent evidence shows that strong enforcement can highly increase

TURF returns (Davis et al. 2015), maximum revenues will be achieved by maintaining low enforcement costs. Thus, transportation and enforcement costs should influence TURF location (Basurto 2005). As with MPAs, TURF enforcement and transportation costs can be reduced by placing TURFs closer to shore and fishing towns so that they can be monitored from land (Atapattu 1987, Dahl 1988, Basurto 2005, Defeo & Castilla 2005, Ponce-Taylor et al. 2006, Gaines et al. 2010b, Wilen et al. 2012, Davis et al. 2015).

TURFs can also be placed according to the distribution of species that provide ecosystem services. According to MPA research, site selection should consider the distribution of ecosystems previously damaged by fishing, to aid in the recovery of food provisioning services (Airame et al. 2003). In particular, the distribution of habitats and species that facilitate the development of ecotourism can be of great importance for TURF site selection. TURF owners around the world have developed eco-tourism and aquaculture as an alternative livelihood — the most prominent examples can be found in Chile, Japan and Mexico (Ponce-Taylor et al. 2006, Cancino et al. 2007, Wilen et al. 2012) — and choosing TURF locations with these multiple services in mind during the planning process rather than as an afterthought could help make them more successful.

Disturbance, and TURF resilience to disturbance, is not addressed in TURF site selection literature, yet is likely a critical factor for TURF performance. High disturbance levels can directly reduce abundance of target species or the habitats they use, but also indirectly affect TURF performance by increasing uncertainty in the status of the target species, thereby reducing fishermen's incentives for sustainable harvests. According to MPA literature, sites with frequent large-scale disturbances are not good candidates for MPA placement. Thus, following the recommendations for MPAs, if possible, TURF placement should avoid sites susceptible to strong levels of frequent disturbance (Roberts et al. 2003).

Although the protection of vulnerable species and habitats is not central to TURF objectives, it is possible that both can benefit from the presence of TURFs (Holland 2004, Gelcich et al. 2008a, 2012, Wilen et al. 2012, Poon & Bonzon 2013). From a conservation perspective, protection of vulnerable species and habitats typically requires full restriction of fishing activities. However, when fishing prohibitions are difficult to impose, TURFs can serve as a tool for some protection. Indeed, the protection of non-targeted species and vulnerable habitats is a common objective of TURFs (Gelcich et al. 2012, Orensanz & Seijo 2013, Poon & Bonzon 2013). For example, in Chile, fishermen use repopulation programs and habitat restoration to enhance species that are not commercially valuable but that serve as prey for the main targeted species (Cancino et al. 2007). Inclusion of critical habitats in the design of TURFs may also indirectly benefit target species, and thus sustainable harvests, when those habitats are used by a life stage of the species. However, the capacity of TURFs to protect these species is likely limited, such that CMPAs should be used for high conservation priority locations.

While not currently considered in TURF literature, the inclusion of a gradient of habitats within a TURF should increase ecological resilience, benefiting overall ecosystem health, and thus TURF owners. The inclusion of different habitats can increase the productivity and health of the resources on which fishing activities depend, particularly in cases where the targeted species performs ontogenic or daily migrations (Roberts et al. 2003, CDFG 2008, IUCN-WCPA 2008). For example, with Japanese satoumi, integrated management of land and coastal areas is performed by TURF owners and has resulted in productive sustainable TURF systems (Berque & Matsuda 2013).

### Shape

Guidelines for the shape of an MPA focus primarily on the need to have clear boundaries to facilitate enforcement (IUCN-WCPA 2008) (Table 3). Clearly defined boundaries help monitoring and surveillance activities in both MPAs and TURFs (Christy 1982, IUCN-WCPA 2008, Defeo & Castilla 2012). In particular, boundaries based on local geological features that are clearly identified, or square shapes that can be clearly georeferenced, as well as shapes that reduce the area-to-perimeter ratio (i.e. squares instead of rectangles), facilitate enforcement (Atapattu 1985, Dahl 1988, Defeo & Castilla 2005, Ponce-Taylor et al. 2006, IUCN-WCPA 2008, Wilen et al. 2012).

## LESSONS FOR TURF NETWORK DESIGN

In most conditions, MPAs should be established as part of a network, since connectivity between reserves is beneficial for biodiversity conservation, supports healthy fish populations, reduces the effects of disturbance and mitigates conflicts with fishing activities by distributing the total area protected over a number of smaller MPAs (Hastings & Botsford 2003, Roberts et al. 2003, Green et al. 2014).

We found that none of criteria used for the design of MPA networks is currently addressed in TURF literature. TURF networks are recommended to avoid the consequences of a mismatch between the distribution of the targeted species and the size of fishing communities' marine territories (Poon & Bonzon 2013). However, TURF networks can be designed to better match the local ecological conditions, suggesting that important lessons can be drawn from MPA literature.

The size, location and shape of individual MPAs within networks is guided by the same criteria for individual MPAs discussed above. However, in order to reduce tradeoffs between conservation and fisheries objectives, scholars have suggested that networks should include reserves of variable sizes, particularly in places with high fishing pressure (Halpern 2003, Roberts et al. 2003, Meyer et al. 2007, Green et al. 2014). In such an arrangement, large reserves help achieve conservation objectives (Roberts et al. 2003) while small to intermediate sized reserves (i.e. tens of kilometers) help support fisheries objectives. Smaller MPAs also provide conservation benefits (Halpern & Warner 2003, Guichard et al. 2004), can be located and designed to meet requirements of different species and habitats and can help spread risk (Halpern & Warner 2003, Shanks et al. 2003, Kaplan et al. 2009, Gaines et al. 2010b).

These criteria have received little attention from TURF researchers. Existing guidelines for TURF network design recommend that the TURF network should be sized to match the distribution of the targeted species, and each TURF should match the fishing grounds of each fishing community (Poon & Bonzon 2013). In the presence of constraints for the placement of large TURFs, a network system can allow for successful small TURFs that match the social landscape, but control harvests over a large portion of the resource as a group (Poon & Bonzon 2013). The level of success of such networks will depend on the level of cooperation among TURF owners within the network and the level of open access fishing effort between TURFs (Aceves-Bueno et al. 2017).

## Size

Total area covered by an MPA network strongly influences the biological and socioeconomic outcomes of the network (Friedlander et al. 2003). The proportion of habitat to be protected within a region depends on regional fishing pressure, fisheries regulations outside the MPAs, the level of human and environmental disturbance and the mobility of the organisms that influences the proportion of species' home range that is contained within the network area (Friedlander et al. 2003, Green et al. 2014). Larger MPA networks are more effective for highly mobile species since they can cover a bigger portion of the total distribution range of the species (Botsford et al. 2003). Currently, most scholars recommend protecting 30–50 % of the management area in order to maintain biodiversity and maximize yields, although 20 % can be sufficient in places with lower fishing pressure (Airame et al. 2003, Friedlander et al. 2003, Halpern & Warner 2003, Green et al. 2014). Where possible, a precautionary approach to MPA network design suggests larger areas to mitigate risk from catastrophic events. For example, in the Channel Islands, California, an 'insurance multiplier' was used (1.2–1.8 the size of the reserve network) to address potential oil spill or storm disturbances (Airame et al. 2003).

Where discussed, it is recommended that a network of TURFs covers the entire range of the harvested species (Poon & Bonzon 2013); with the right conditions of cooperation among TURF owners, this arrangement should be sufficient to allow the maintenance of the harvested populations. However, this arrangement overlooks important ecological aspects considered in MPA literature, such as the reduction of the effects of disturbance and the importance of connectivity for the maintenance of healthy marine habitats (Friedlander et al. 2003, Green et al. 2014). Due to the lack of empirical evidence and recommendations regarding the appropriate TURF network size, we recommend following the guidelines of MPA networks as a precautionary approach that allows the maintenance of the targeted species and its key habitats. As such, guidelines for MPA design with respect to total network area can be applied directly to TURF network design (Table 4). This recommendation can be set as a design goal and modified according to the local governance, social and political factors.

## Location

Biogeographical representation is not a criterion for designing TURF networks since it is meant to address a conservation rather than resource extraction objective. However, MPA network design criteria also emphasize replication and heterogeneity when choosing MPA locations (Table 4). For example, it is recommended that at least 3 instances of each major habitat should be included within the network (Green et al. 2014). Incorporating different habitats in the design of TURF networks could not only increase the resilience of the biological system but also provide local communities with a wider option of fishery targets, facilitating adaptation to environmental and economic impacts and increasing overall resilience of the socio-ecological system (Adger 2000, Zhou et al. 2010, Poon & Bonzon 2013).

### Spacing

MPA design theory emphasizes the need for connectivity among habitats (Parnell et al. 2006). To facilitate this connectivity, appropriate spacing between individual MPAs should be small enough to allow the spillover of materials (such as organic carbon), adult fish and larvae, but big enough to diminish the effects of large catastrophes (Roberts et al. 2003, Gaines et al. 2010b, Morel et al. 2013, Burgess et al. 2014, Green et al. 2014). Precise spacing is difficult to achieve since it depends on the dispersal capacity of many species, each with different dispersal patterns. However, in general the recommended spacing for MPAs is 10–20 km (Halpern & Warner 2003, Shanks et al. 2003, Green et al. 2014), although some authors consider 50–100 km as more appropriate (CDFG 2008). Ultimately, it may be most effective to space reserves at varying distances from each other (Airame et al. 2003).

TURFs within a network will also be connected to one another, such that the actions in one TURF will affect the other ones (González et al. 2006). The appropriate spacing in a TURF network has been poorly studied. As with MPAs, smaller distances between TURFs would enhance connectivity and facilitate the maintenance of healthy and productive harvesting areas. However, in contrast with MPAs, the desired level of connectivity varies with level of cooperation among TURF owners. If the level of cooperation between TURF owners is high, the reduction of open access areas, and the high levels of connectivity could allow them to behave as a single large TURF, which could in turn translate into higher yields. In the presence of low levels of cooperation, larger TURFs separated by larger distances or MPAs could be preferable to ensure exclusivity in access to the resources and avoid competition among TURF owners (Costello & Kaffine 2010).

## DISCUSSION

TURF design theory remains relatively nascent. As such, the extensive work on MPA design offers a unique opportunity to accelerate TURF design theory, and ideally avoid some of the earlier missteps in MPA creation. In particular, TURF design guidelines currently focus almost exclusively on social criteria, ignoring most ecological considerations (Tables 3 & 4). This focus is unsurprising, since TURF success heavily depends on the appropriate alignment of incentives for sustainable use, and has led to a large body of literature on the effect that social conditions have on defining the appropriate size, location and shape of TURFs. For example, most authors recognize that incorporating local traditions and rules is critical for TURF success (Dahl 1988, Defeo & Castilla 2005, Aswani et al. 2007, Aburto et al. 2013, Yates & Schoeman 2015). Successful TURFs have to match the area of operation of user groups with a strong capacity for self-governance (Aswani et al. 2007, Wilen et al. 2012) as well as create appropriate conditions to limit the access to outsiders (Dahl 1988, Cancino et al. 2007). Less frequently addressed but equally important, social constraints can be particularly challenging when creating TURF networks. When a large proportion of the resource is shared between different extractive areas within a network, cooperative schemes among TURF owners need to be developed in order to avoid a race to fish and the over-exploitation of resources (Aceves-Bueno et al. 2017).

However, since TURF economic success fundamentally depends on the conditions of the targeted species, TURFs should be designed around ecological principles as well. Incorporating the lessons from MPA design into TURFs can facilitate the development of ecosystem-based management (EBM) schemes in TURFs. Many TURF systems around the world were created with the objective of managing a few commercially relevant species (Gelcich et al. 2010a, McCay 2017). However, important advantages can be accomplished by taking a more integrative management perspective. In recent years, MPA theory and design has increasingly taken an EBM approach (Halpern et al. 2010). These efforts have resulted in important lessons to improve the inclusion of ecological criteria in TURF design and maximize sustainable productivity. In particular, the design criteria for CMPAs can be used to inform design guidelines for individual TURFs (Table 3). Based on our findings, we recommend that TURF site selection should account for the distribution of critical habitats for the targeted species; to achieve this may require creating larger TURFs to increase the possibility of including critical habitats. We also recommend avoiding locations with high levels of disturbance, or when disturbance is unavoidable, creating larger TURFs and TURF networks with individual TURFs separated by longer distances. Finally, considering the location of historical fishing grounds for TURF site selection might help recover heavily exploited fishing targets.

Similarly, design criteria for MPA networks offer valuable insights for TURF design; notably, none has yet been considered in the TURF literature. The disconnect is understandable since MPA network design relies mostly on ecological criteria while TURF network design is primarily concerned with matching social functional units with the distribution of targeted species (Table 4). Yet as we note above, sustainable TURFs require healthy, well-connected, functioning ecosystems, and MPA network design theory helps inform how to achieve that goal. Where possible, TURF networks should include multiple representative habitats, and replicates of each, since doing so can increase the resilience of the socio-ecological system. Finally, we recommend following MPA site selection guidelines that promote selecting sites close to each other to allow the transference of resources and materials between neighboring sites and facilitate face-to-face communication when co-operative schemes between TURF owners can be developed (Ostrom 1998).

If applied, these recommendations could help the development of strongly performing TURF systems. However, it is critical to consider potential challenges in the implementation of these design guidelines. As with MPAs, the design of TURFs and TURF networks will likely be constrained by the local social and economic conditions. Common challenges during the implementation process of MPAs and TURFs are the lack of funding and the conflicts between stakeholder groups with opposing views and priorities (Botsford et al. 2003, Poon & Bonzon 2013). In TURFs, perhaps the biggest challenge is preventing social conflicts resulting from the exclusion of a portion of the resource users. The guidelines presented here suggest that access rights should be granted to one social functional unit per fishing area (Poon & Bonzon 2013). The identification of those social functional units can be quite complex, and the question of who merits exclusivity of access to a particular fishing ground tends to be controversial. In Chile, the inequity in access rights has led to severe conflicts between the management agencies and fishermen, and among groups of fishermen, which could be incentivizing illegal fishing activities (González et al. 2006, Gelcich et al. 2007, Aburto et al. 2013). Understanding the local social landscape prior the implementation of the TURF can help reduce conflict and improve compliance.

Fortunately, TURF research has resulted in a large body of literature that addresses the social dynamics behind TURF implementation. Although it was not the main objective of this paper, in this regard TURF literature can provide important lessons to MPA design theory. In recent years TURF research has made important contributions to the theory regarding co-management, cooperation, equity, community based management and enforcement, as well as in the incorporation of the use of local ecological knowledge, traditions and heritage in decision making (Aswani 2005, 2017, Basurto 2005, Gelcich et al. 2006, 2007, 2008b, González et al. 2006, Berque & Matsuda 2013, McCay et al. 2014, Santis & Chávez 2015, Defeo et al. 2016). The results of these efforts could ease the implementation and maintenance of both TURFs and MPAs. A full review of TURF design guidelines, as well as the lessons that TURF literature can provide to MPA design guidelines, is an important research topic that should be developed in future studies.

TURF research is opening the door for the development of a new wide range of management schemes that require the development of unique design guidelines. Although we identified several similarities and lessons of design between TURFs and MPAs, our study also shows interesting and important design differences between these tools. The objective of a TURF is to achieve sustainable harvests within its boundaries. In contrast, the aim of CMPAs is to preserve resources inside the area's boundaries, while the objective of FMPAs is to enhance fisheries outside adjacent to the management area. These differences in goals affect the desired level of spillover and management feasibility, both of which affect the size of the management area. For instance, in a TURF, best results are achieved by reducing the level of spillover. In contrast, a strong performing FMPA would be the one with the highest levels of spillover to the adjacent fisheries. As a result, the recommendation for TURF size can result in larger areas than those recommended for a FMPAs.

We also found differences in the design conditions that improve management feasibility. Although, as with MPAs, larger TURFs have a smaller boundary area to be protected (in relation to a series of small TURFs), TURF design also has to facilitate strong enforcement and monitoring of the fishing activities within their boundaries. Larger TURFs tend to involve a larger and more heterogeneous group of fishermen. Thus unlike in the case of MPAs, in TURFs larger sizes do not necessarily facilitate management and enforcement. When the enforcement of fishing activities is challenging inside the TURF, smaller sizes might be desirable.

Lastly, unlike MPAs, which can restrict human interaction with the ecosystem, TURFs allow the development of sustainable fishing activities and 'active conservation' measures, resulting in low levels of social stress compared to those caused by full human exclusion (Berque & Matsuda 2013). In fact, many TURF owners have developed strategies to enhance productivity and ecosystem health. In Japan, some of these activities include river basin forestry, sea grass transplants, artificial tidal flats, aquaculture and kelp forest restoration, which ultimately makes TURFs 'intensive marine farming operations' that shape the marine territory to increase productivity by considering the local geological conditions, currents and habitats (Cancino et al. 2007, Wilen et al. 2012, Berque & Matsuda 2013). TURFs can be designed with enough flexibility to adapt to changes in social and natural conditions through adjustments in the access rights, for example by incorporating transferability and/or through inter-TURF cooperation (Panayotou 1984). The presence of TURFs may also add resilience to the system since 'potential benefits from such a TURF system may increase the inherent community resilience of the system by enhancing the practical capacity to cope with disruption' (Camp et al. 2015, p. 8).

Missing from this review is the potential to combine MPAs and TURFs (so called 'TURF-reserves'), which could help reduce potential tradeoffs between maintenance of healthy ecosystems and sustainable harvests (Costello & Kaffine 2010, Micheli et al. 2012, Afflerbach et al. 2014, Barner et al. 2015, Gelcich & Donlan 2015), as well as the potential for integrating TURFs into broader marine spatial planning. Additional design criteria will likely be needed for these more comprehensive planning efforts. In the meantime, however, TURF design can make rapid advances by borrowing from the extensive and well-tested MPA design theory.

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