Rotational zoning systems in multi-species sea cucumber fisheries

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Abstract

Rotational zoning systems (RZSs) have been applied as a spatial management tool for fisheries in developed countries. Fishing grounds are divided into numerous plots and assigned a cyclical periodicity for harvest. This is a distinct spatial management measure that differs from more common measures in the tropics, like periodic closures or marine protected areas. We find that biological prerequisites for rotational closures are tenuous for many tropical reef species, and they are likely to put stocks of threatened species at further risk. RZSs can be successful if enough is known about the biology and ecology of target species, if the rotational cycles are long enough to allow population recovery, and if there is enough technical capacity to plan, implement and enforce management measures. However, RZSs are likely to fail in small-scale fisheries in the Pacific Islands and low-income countries owing to a combination of modest technical capacity for planning and monitoring, weak enforcement, complex access rights to fishing grounds, and high numbers of fishers.

Introduction

Rotational zoning systems (RZSs) are a relatively new management tool for sea cucumber fisheries. They have been called “rotational zoning systems” (Lowden 2005), “rotational harvest closures” (Purcell 2010) and “rotational zone strategies” (Plagányi et al. 2015).

The concept of RZSs is to subdivide fishing grounds into zones, and nominate zones to be fished in a certain year but not other years, in a cyclical fashion. For example, one-third of the zones are fished in the first year, the second third of the zones are fished in the second year, and the last third of zones are fished in the third year; then the cycle is repeated. This allows populations in each zone to be unfished for two years after each year of fishing. Such a scheme has been practised since 2004 on the Great Barrier Reef (GBR), where a portion of the fishing grounds is divided into 156 zones (Lowden 2005) (Fig. 1). These zones on the GBR have a broad range of shapes and sizes.

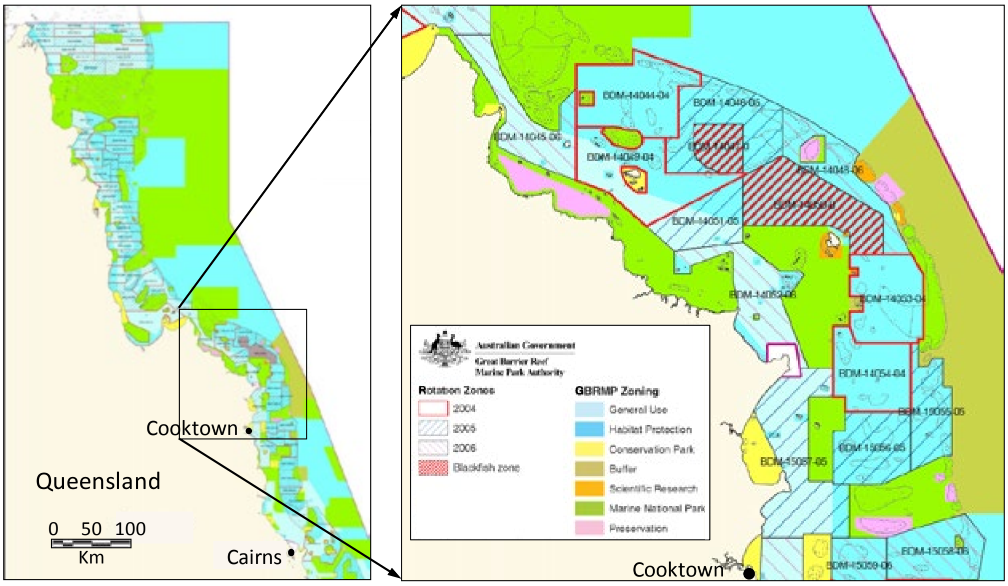

Figure 1. Northern section of the Great Barrier Reef (left), with enlarged section showing rotational zones of the east coast sea cucumber fishery in the Cooktown region (right). At least 15 species can be fished in plots every 3 years in the rotational cycle. Map courtesy of the Great Barrier Reef Marine Park Authority, with modification.

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Canada began a rotational-style fishery for its Pacific region sea cucumbers in 1993 but moved to an annual style fishery in 1997 (DFO 2014) (Fig. 2). Following a review, the Pacific region fishery returned to a three-year rotational style fishery in 2011. As on the GBR, some portions of the coast are closed to fishing. The fishery also relies on stock assessments, through research collaboration between fishers and the fishery agency, to determine a triennial harvest rate of approximately 10% for each zone, equivalent to a 3.3% annual harvest rate. The management plan explains that the RZS allows fishers to reduce costs of travel to fishing grounds and staffing of multiple offloading ports (DFO 2014). This is a feature of industrial-scale fisheries, and is different to artisanal fishers in the tropics where fishers are only accessing local grounds.

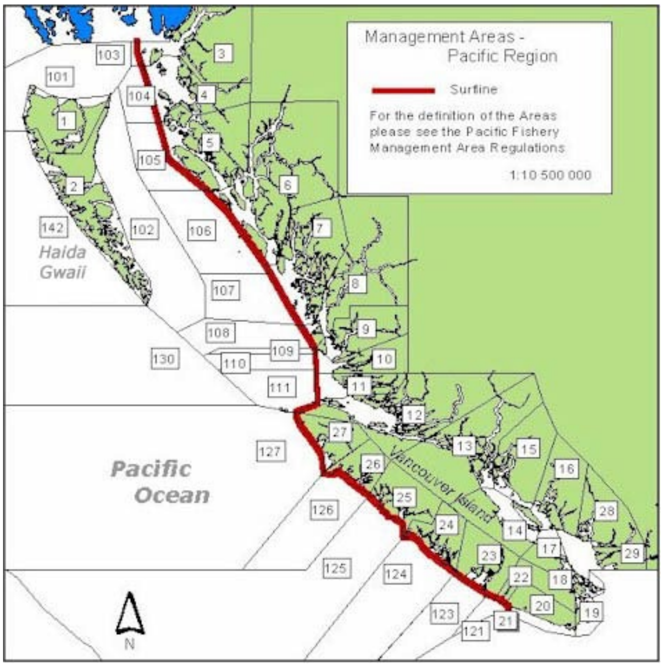

Figure 2. Rotational zones in the single-species specific sea cucumber fishery in British Columbia, Canada. *Parastichopus californicus* is fished in plots every three years in the rotational cycle. Map courtesy of the Department of Fisheries and Oceans Canada. Note that the map does not show areas closed to fishing and does not show new areas recently opened to fishing.

In Alaska, the entire fishery is managed under an RZS with one-third of the 46 areas of the sea cucumber fishing grounds open each year (Fig. 3). These grounds are subject to fishery-independent biomass surveys. The management authority states that "the 3 year rotation was put into place as a means of reducing management costs for surveys and management, and not as a method to allow stock rebuilding between harvests" (ADFG 2016). Fishers "expressed concerns that favorite harvest areas are not recovering between each three year rotational harvest", although this may not be the case across the fishery (ADFG 2016).

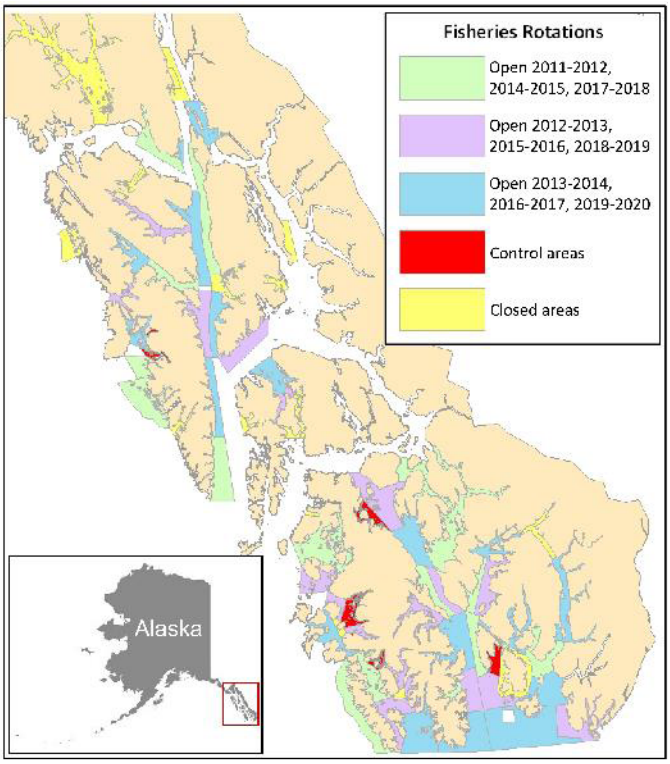

Figure 3. Rotational zones in the (monospecific) sea cucumber fishery in Alaska. *Parastichopus californicus* is fished in plots every three years in the rotational cycle. Map courtesy of the Alaska Department of Fish and Game, with modification.

Caution has been raised about the use of RZSs in multi-species fisheries such as those in the Indo-Pacific, because the approach assumes fast recovery of sea cucumber populations, which may not be true for many target species (Lincoln-Smith et al. 2006; Purcell 2010; Friedman et al. 2011). For instance, after the reduction of Chinese imports of beche-de-mer product following the Cultural Revolution, sea cucumber populations in previously fished areas slowly recovered over 50 years (Conand and Byrne 1993). A similar timeframe was estimated for full recovery of black teatfish populations fished on the GBR (Uthicke et al. 2004). Implementation of RZSs also requires significant investment in planning and surveillance, which is unlikely to be resourced in most low-income countries in the Indo-Pacific (Purcell 2010).

The merits of rotational zoning for the portion of the GBR sea cucumber fishery managed under this scheme were recently assessed through computer modelling of various biological data (Plagányi et al. 2015). For Pacific Island and low-income country fisheries, this management strategy is considered to be inappropriate (Purcell et al. 2015). Here we assess some of the assumptions and data on biological traits that underpin the design of RZSs, and discuss challenges in applying the strategy to multispecies sea cucumber fisheries in the Indo-Pacific.

Appraisal

Analogy with crop rotations?

Rotational harvesting is an agricultural concept that has been applied in multi-species sea cucumber fisheries in Australia (Lowden 2005), and single-species fisheries in Alaska (ADFG 2016), Washington state (Hamel and Mercier 2008) and western Canada (DFO 2014). In terrestrial farming, different crop species are rotated from one year to another in order to maintain soil quality. Plots of land can also be left fallow for a year or more to allow natural regeneration of soil properties.

"Crop rotation" principles are not directly relevant in natural marine ecosystems because marine animals are not seeded as crops are in agriculture, and they do not have the predictable production times of plant species to be confident in rotational cycle periodicity (Purcell et al. 2015). In addition, wild stocks in fisheries are not grown in controlled conditions. Instead, they are subject to natural reproductive limitations and variability in recruitment from year to year. In agriculture, habitat quality can be directly assessed and monitored for suitability for particular commercial species and soils can be fertilised for productivity – attributes not possible in the sea. Therefore, application of crop rotation principles in fisheries for relatively sedentary benthic species like sea cucumbers is tenuous. RZSs in the sea cannot be likened to crop rotation in agriculture.

Biological pillars for RZSs

The rationale underpinning RZSs is that wild populations are fished and then left for some years, during which time small individuals grow to harvest size and stocks are repopulated through natural recruitment. However, natural recruitment tends to be unpredictable and irregular for many marine species (Uthicke 2004; Friedman et al. 2011), due to annual variations in climatic and hydrological conditions that favour or disfavour reproduction, larval supply and settlement processes of planktotrophic larvae. To have confidence in rotational closures, it is important to assess whether commercial species in the fishery have fast growth rates and regular annual recruitment (Purcell 2010) and are not vulnerable to Allee effects. Sea cucumbers are highly vulnerable to Allee effects where spawner density is low (Bell et al. 2008).

Although early studies using size-based growth models (developed for finfish) indicated reasonably fast growth rates of some tropical sea cucumbers (Conand 1989), more recent studies using more sophisticated methods suggest that growth is much slower for some species (Uthicke and Benzie 2002; Uthicke et al. 2004). Models used to estimate the performance of RZSs on the GBR are quite liberal with data inputs on growth rates, and likely to result in the model predicting overly short rotational cycles. For example, for the black teatfish *H. whitmaei*, Plagányi et al. (2015) used an age at maximum length of 5–10 years and an age at first maturity of 4 years. This means that animals become mature at 4 years old, at which they are about 26 cm, then reach maximum length of 56 cm perhaps as little as one year later. Such fast growth in the wild is not possible, and is contrary to empirical studies that show much slower growth in this species (Uthicke and Benzie 2002; Uthicke et al. 2004). Clearly, more conservative inputs are needed with such models, especially for the teatfish species (*H. whitmaei*, *H. fuscogilva* and *H. nobilis*), which are threatened globally (Conand et al. 2014). On the other hand, some smaller species in the stichopodid group, such as *Stichopus chloronotus*, are likely to have comparatively fast growth rates (Conand 1988). In addition to species' biology, habitat variables and environmental productivity influence their abundance and growth (Conand 1989; Lee et al. 2008; Bellchambers et al. 2011). Together, these factors highlight the risk of a "one-size-fits-all" management approach to multi-species sea cucumber fisheries across heterogeneous environments, where different species have vastly different abundances, life history traits and growth trajectories.

A second biological pillar of RZSs is that species have regular recruitment so that population losses to fishing are replenished in zones in non-fishing years. Rotational cycles are commonly three years, so populations have two years in which to recover from fishing. Skewes et al. (2010) showed that black teatfish *H. whitmaei* populations recovered "to near natural (unfished) densities" after seven years of fishing closure in the Torres Strait fishery. However, recovery elsewhere may be very slow due to irregular recruitment, such as on the GBR (Uthicke 2004) and Tonga (Friedman et al. 2011). Similarly, recruitment and population recovery after 3–10 years of fishing closure may occur for some coral reef holothuroids but not others (Lincoln-Smith et al. 2006; Friedman et al. 2011). Thus, population recruitment appears spatially and taxonomically variable, likely species-specific, and the evidence for coral reef species does not give confidence that a three-year rotation is appropriate in a multi-species fishery unless fishing is highly conservative. This is a different case to fishing periods allowed with other management measures because the rotational closures generate more intense fishing in open zones each year when other zones are closed.

Management strategies should be particularly cautious for threatened species. Harvest cycles for species assessed by the International Union for the Conservation of Nature as being threatened globally with extinction (e.g. *Holothuria fuscogilva*, *Stichopus herrmanni* and *Thelenota ananas*) should be more conservative (e.g. 7–10 years) than for less vulnerable species. Computer modelling of the RZS region of the GBR fishery (Plagányi et al. 2015) suggests a 1 in 10 chance of depletion of black teatfish (*Holothuria whitmaei*) under the scheme. This is arguably unacceptable for an endangered species, which should be managed with much less perceived risk.

Success of RZSs in sea cucumber fisheries

RZSs have been running for a portion of the multispecies GBR fishing grounds for 11 years and for all the fishing grounds in the single-species Alaskan and British Columbian fisheries for 25 and 4 years, respectively. The success of this strategy as a sustainable management tool is indicated if catch rates are maintained for valuable species and if fishers do not need to switch to other species (Friedman et al. 2008).

On the GBR, catches for high-value white teatfish (*Holothuria fuscogilva*) and prickly redfish (*Thelenota ananas*) have both declined under the RZS. The last available fishery report shows roughly 50% lower catches of white teatfish in recent years than before 2003–2004, and reports declines "by approximately 3.5 t" in both of the last two years of reported fishing (DAFFQ 2012). That report also states that "Prickly redfish catch decreased again from approximately 42 t in 2008–09 and 21 t in 2009–10 to 17 t in 2010–11", reflecting a decrease by over 50% in catch. Decreases in catches were believed to be the result of greater focus by fishers on curryfish, and the report claims that "Prickly redfish is a less valuable species in comparison to other harvestable species" (DAFFQ 2012), although market data show otherwise (Purcell 2014). In addition, fishers have switched to other species and also operate in areas that are not managed under the RZS (Eriksson and Byrne 2015). These are symptoms of overexploitation of more accessible, shallow-water, high-value species (Friedman et al. 2008; Eriksson and Byrne 2015). Fishers should not need to look to development of new processing methods for lower value species if high-value species remain in abundance. More in-water science is required for assessment than is commonly perceived or presented when RZS outcomes are analysed.

In Canada, questionnaire surveys showed that the majority of fishers perceived abundance and catch rates to have declined and "harvesters most commonly cited overfishing as the most pressing problem facing the fishery" (O'Regan 2015). In that rotational harvest fishery, fishers attributed overfishing to "licence quotas being set too high, the annual harvest not having allowed sufficient recovery time, and overestimates of quota-management-area biomass" (O'Regan 2015). Fisher perceptions therefore indicate that, for various reasons, the rotational harvest strategy in western Canada has not been successful at maintaining stock abundance.

Applicability for Pacific Islands and low-income countries

RZSs have only been applied in developed countries, which have much higher governance capacity than, for example, Pacific Island countries (Fig. 4). Weak governance can of course be said to influence performance of all fishery management, but our point is that measures cannot simply be transferred across "the capacity gap". Strategies for fishery management need to be developed on a case-by-case basis considering contextual factors, including capacity.

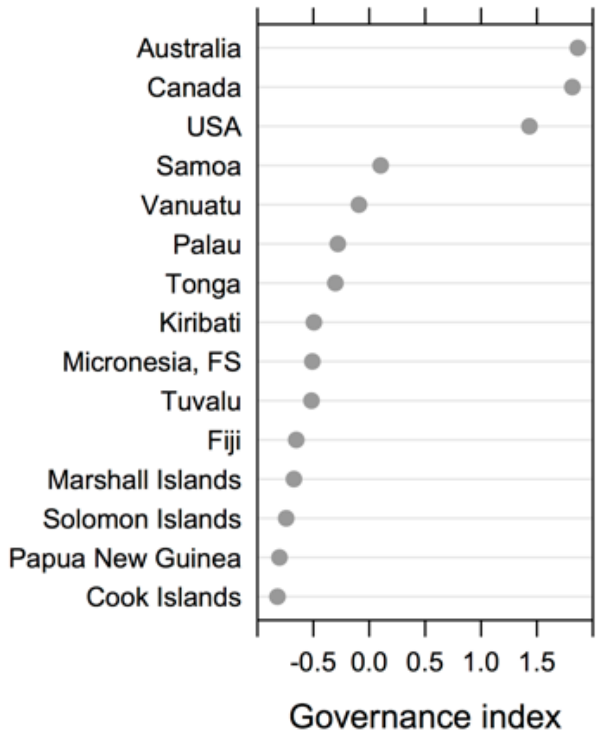

Figure 4. Composite governance index for year 2011, based on metrics for national "Government effectiveness", "Regulatory quality", "Rule of law" and "Control of corruption" in the Worldwide Governance Indicators by Kaufman et al. (2010).

We see three important factors in the three RZS fisheries that differ from most of the sea cucumber fisheries in the tropical Indo-Pacific and Caribbean. Firstly, they are managed by agencies with high technical capacity to plan and implement sophisticated management measures. Second, the agencies have high capacity for surveillance and enforcement, such as the satellite-monitored vessel monitoring systems used on the GBR. Third, there are very few fishers. In Australia just two fishing companies harvest sea cucumbers within the GBR. In British Columbia, Canada, there are 85 licences in the sea cucumber fishery and usually two divers per vessel (DFO 2014). In Alaska, there were 276 permits for the Southeast fishery and 30 permits for the Kodiak Island fishery for the 2015 season (M. Donnellan, pers. comm.). In contrast, fisheries that predominate in the Indo-Pacific mostly have weak capacity to plan management measures and conduct enforcement (FAO 2013; Purcell et al. 2014) and have hundreds, thousands or even hundreds of thousands of fishers (Purcell et al. 2013).

The planning of RZSs requires a lot of information and technical capacity to map out the zones. For successful implementation, fishery managers need extensive geographic and social information about where the rotational zones can be situated and how big they should be. We therefore doubt that RZSs can readily be applied in Pacific Island fisheries, or in most other artisanal-style fisheries throughout the Indo-Pacific. In addition to insufficient technical capacity for planning and surveillance of RZSs, it is unlikely that the scheme will be socially compatible, accepted and understood by the thousands of village fishers in coastal and island nations. For example, marine tenure in most Melanesian countries restricts fishers to certain fishing grounds, which would each need to be divided into zones and designated a cycle periodicity in order for fishers to have income year after year. Unless a co-management model can be found, a centralised zoning scheme may also disenfranchise customary resource owners, which seems to be a step away from current Pacific coastal fisheries policy in which communities are encouraged to have a stronger role in managing fisheries (SPC 2015). RZSs may prevent fishers from accessing nearby fishing grounds in the years when those plots are closed in the rotational cycle. Issues of access rights were legally challenged by American First Nation tribes when the fishery in Washington used a RZSs, and the rotational system was abandoned (Bradbury 1994).

Conclusions

We conclude that rotational zone closures are only applicable to fisheries in developed nations that have a high technical capacity to plan rotational plots and gazette them for the fishery, that have sophisticated surveillance, and that have few fishers. That said, even in developed nations RZSs are not without biological uncertainties and access issues. Rotational cycles must be long enough to allow species with slow growth and irregular recruitment to recover before being fished again, and this is very likely be more than five years for certain species depending on fishing effort. Particular caution needs to be implemented for species vulnerable to extinction.

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