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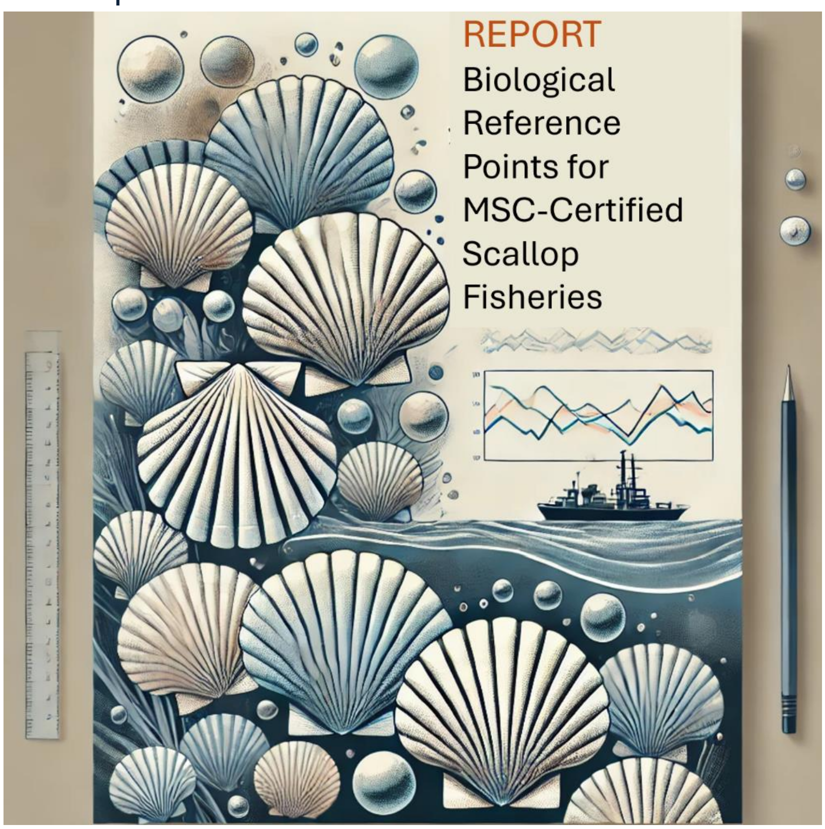

Autores: Pedro Daleo
Instituto de Investigaciones Marinas y Costeras (IIMyC) UNMdP-CONICET
Mar del Plata, Argentina

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Informe

REVIEW OF BIOLOGICAL REFERENCE POINTS (BRPS) AND HARVEST CONTROL RULES (HCRS) USED BY MSC-CERTIFIED SCALLOP FISHERIES AS WELL AS FOR OTHER (MOSTLY) SEDENTARY BENTHIC SPECIES

Pedro Daleo[1]

[1]Grupo de Ecología.
Instituto de Investigaciones Marinas y Costeras (IIMyC).
Departamento de Biología, Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Mar del Plata.
Consejo Nacional de Investigaciones Científica y Técnicas (CONICET),
Mar del Plata, Argentina.

ABSTRACT. Biological reference points (BRPs) are a fundamental part of the precautionary management of fishing resources since they allow defining safe exploitation levels. Most BRPs reflect maximum fishing pressures or minimum stock biomass levels that are determined using historical abundance data and life history parameters of the exploited species. In mostly sessile species with a pelagic larval stage, the recruitment and biomass of the stocks generally present great temporal variability and cyclical patterns, with a poor stock-recruitment relationship, which is a challenge for obtaining analytical BRPs. Review of the MSC-certified scallop fisheries, and fisheries of other mostly sessile organisms, show that there is variability both in the used BRPs (both analytical and empirical PBRs are observed), in the methods to obtain/estimate these values and in the associated harvest control rules. The selection of BRPs for setting harvest control rules is generally determined by the management objectives and biological characteristics of the resource but also by the type and amount of information available.

RESUMEN. Los puntos biológicos de referencia (PBR) son parte fundamental para el manejo precautorio de los recursos pesqueros ya que permiten definir niveles seguros de explotación. La mayor parte de los PBR reflejan presiones de pesca máximos o niveles de biomasa del stock mínimos y están determinados utilizando los datos de abundancia históricos y los parámetros de historia de vida de las especies explotadas. En especies mayormente sésiles y con estadío larval pelágico, el reclutamiento y biomasa de los stocks presentan generalmente gran variabilidad temporal y patrones cíclicos, con una pobre relación stock-reclutamiento, lo que genera un desafío para la obtención de PBR analíticos. Los resultados de la revisión de las pesquerías de vieira, y de otros organismos mayormente sésiles, actualmente certificadas por el MSC muestran que existe variabilidad tanto en los PBR utilizados (donde se observan tanto PBR analíticos como empíricos), como en los métodos para obtener/estimar dichos valores y en las reglas de control de captura asociadas. La selección de PBR para las reglas de control de captura están generalmente determinados por los objetivos de manejo y las características biológicas del recurso pero también por el tipo y la cantidad de información disponible.

Key words: Biological reference points, certified fisheries, harvest control rules, Marine Stewardship Council, sedentary species, scallops.

Palabras clave: Especies sedentarias, pesquerías certificadas, puntos biológicos de referencia, reglas de control de captura, vieiras.

INTRODUCTION

Successful management of fishery resources is essential not only to preserve biodiversity but also for the stability of social well-being. From a population dynamic perspective, fisheries are a source of fishing mortality (as senescence, predation, diseases and food shortage, among others) whose magnitude depends on fishing efficiency (i.e. catch per unit effort (CPUE)) and fishing effort (Rijnsdorp et al. 2006). As population dynamics (i.e. temporal changes in stock abundance or biomass) directly depend on recruitment, growth and mortality, when the losses by mortality exceed the gains by recruitment and growth, the stock decreases (Gebremedhin et al. 2021). Generally, this imbalance is a consequence of excessive fishing mortality, driving to impaired stock resilience and productivity and making the fishery unsustainable, a scenario known as overfishing (Orensanz et al. 2016).

The main issue related to overfishing is that recruitment (reproduction) can be affected by depensatory dynamics and, thus, reduced mortality may be insufficient to allow recovery after severe stock decreases (Myers et al. 1995, Gebremedhin et al. 2021). As a response to generalized fishery collapses during the 1990s, fishery scientists started to develop population dynamics models that allow avoid overfishing by evaluating and forecasting stock status under different management strategies (Quenn 2003). In this context, biological reference points (BRPs) emerged as a key tool for precautionary management as they provide assessment and allow setting clear harvest control rules for the efficient management of stocks (Hilborn et al. 2020).

There is a great variety of BRPs both in the literature and in practice (Silvar-Viladomiu et al. 2022) but, despite this diversity, most of them are relatively simple metrics, or measurements, reflecting the relative stock status from a biological perspective (Gabriel and Mace 1999). The most commonly used BRPs are pre-determined stock biomases (B) or fishing mortalities (F) that correspond to either a desired (target), or the threshold to an undesired (limit), state of the stock (Orensanz et al. 2016). Target reference points can be B or F levels that allow the long term optimal harvest (Caddy y Mahon 1995). This idea is grounded on the theoretical existence of a stock biomass level (B_{MSY}) and a fishing mortality rate (F_{MSY}) that allow the largest catch over an indefinite period (i.e., ensure the maximum sustainable yield (MSY)). This theoretical concept, in turn, is grounded on the idea that a population pushed below its carrying capacity experiences an increase in productivity as a result of compensatory dynamics (e.g., decreased mortality and/or increased growth and reproduction driven by decreased competition; Orensanz et al. 2016). Limit reference points, instead, are biomass (B_{LIM}) or fishing mortality rates (F_{LIM}) beyond which there is a high probability of impaired resilience and decreased long term productivity as a consequence of overfishing.

Under the precautionary approach, HCRs usually determine the total allowance catch (TAC) by the actual status of the stock in relation to target and limit reference points (Punt 2010). In order to analytically calculate MSY based reference points (i.e., B_{MSY} and F_{MSY}), nevertheless, it is necessary to build the yield curves knowing (1) the stock-recruitment (S-R) function; (2) the yield-per-recruit (YPR) and the spawning-stock-biomass-per-recruit (SSPR) and (3) different biological parameters and fishing activity patterns (Hilborn y Walters 2013). In sedentary benthic organisms with pelagic larvae, as scallops, the different life history stages involved in recruitment and the processes determining yield and spawning biomass are decoupled in their temporal and spatial scales (Orensanz et al. 2016), leading to diffuse S-R relationships (Hart et al. 2013). Changes in the abundance of populations over time, instead, are commonly more influenced by density-independent effects of climate forcing and ocean circulation, eventually in conjunction with fishing (Orensanz et al. 2016). Thus, standard MSY-based reference points developed for finfish are often unsuitable for sedentary stocks. Initially, scallop fisheries solved this problem by setting the optimal size of capture, as well as target and limit fishing mortalities, using BRPs based on F_{MAX}, the fishing mortality that maximizes YPR (Orensanz et al. 2016). Subsequent progress in modeling and simulation has allowed, at least for some stocks, to estimate probability distributions of B_{MSY} and F_{MSY} even without knowing the S-R function. In other cases, when analytical models can not be applied and/or stock dynamics are naturally variable, empirical proxies of B_{MSY} and F_{MSY}, as well as other reference points like the stock equilibrium biomass before fishing started (B_0), have been estimated from historical data (Caddy 2004). Most recently, given the complex and dynamic nature of these systems and the accelerated rate of environmental change, it has been acknowledged that, in order to achieve stability in the performance of management strategies, HCRs need to incorporate dynamic reference points, flexible enough to account for shifts in ecosystem and species population productivity over time (Collie et al. 2021, Eddy et al. 2023). Given the progress in modeling, such dynamic PBRs, capable of incorporating changes in the life history parameters of the resource (e.g., changes in S-R relationships, mortality or growth), are now possible (Eddy et al. 2023). The selection of reference points for HCRs, thus, should depend on (i) management objectives, (ii) resource-specific and stock-specific biological characteristics, (iii) data availability and (iv) the exploitation history of the stock (ICES 2021). In this context, the objective of this report is to review the BRPs used in the management of scallop fisheries as well as in other sedentary (or mostly sedentary) organisms, and relate them to resource-specific and stock-specific characteristics as well as to the available empirical information/knowledge. To this end, Marine Stewardship Council (MSC) Public Certification Reports were reviewed for certified scallop (and other similar organisms as clams, oysters, mussels, snails, abalone and urchins) fisheries.

METHODS

MSC-certified fisheries of benthic organisms were compiled on January 10, 2024 using the MSC webpage (https://fisheries.msc.org/en/fisheries/) using the keywords: scallop, oyster, clam, snail, mussel, abalone and urchin. For each fishery with a Certified status, the lattest Public Certification Report (from Initial assessment or re-assessment) was reviewed and information about target species biology and distribution, stock characteristics, stock assessment methods, reference points used to determine stock status as well as HCRs based on reference points were recorded. Additional information were searched on the scientific literature when necessary. In addition, to evaluate the BRPs that ICES advice to use to manage scallop and other benthic fisheries in the North Atlantic Ocean and adjacent seas, reports from ICES Scallop Working Group as well as ICES Guidance Reports related to stock assessment and reference points were reviewed.

RESULTS

The 10 scallop fisheries that currently have an MSC Certified status show a great variability in the used BRPs, in the methods used to calculate/estimate such values (see

Table I for a summary) and the use of such values when establishing HCRs.

King scallop (*Pecten maximus*) fishery, Baie de Saint-Brieuc, France

This scallop species is distributed in the NE Atlantic from Norway to Portugal. Data and models suggest that the Baie de St. Brieuc has almost self-recruitment, thus the management is based in considering a single stock (Nicolle et al. 2013). There is a long time series of information on biomass, distribution, size- and age-frequency and recruitment from annual fishery-independent surveys. These data show that both recruitment and biomass is cyclic, with a frequency of 15 years. Stock biomass is directly estimated annually based on a stratified sampling design at fixed stations and there is also an annual survey of spat settlement.

According to Criquet et al. (2022), HCRs are not based on official reference points. This is because standard fixed reference points (e.g., B_{MSY}, B_0) may be not useful for stocks with highly variable and cyclic recruitment and biomass, and with no evidence of a SR relationship. Instead, management advice is provided grounded in qualitative management objectives (retain sufficient biomass each year to ensure that recruitment is maximized and retain sufficient biomass from the large year classes to provide biomass during poor periods and reduce interannual variability in landings). Advice is based on a model that uses the annual direct estimates of biomass and growth, as well as landing data, to estimate total mortality and F for each age class. Given this lack of reference points and clear HCRs, during the MSC initial assesment (2022), the performance indicators for Principle 1 related to stock status and HCRs were evaluated through the Risck-Based Framewor (RBF) analysis. As a result, clear HCRs based on reference points consistent with MSY were required as a condition for re-certification.

King scallop (*P. maximus*) fishery, Shetland Island

Information about the population structure of king scallop in Scotland coasts is limited, thus it is not known whether beds around Shetland Island form a single or multiple stocks, but are considered and managed as isolated from other scallop stocks in Scotland. As reported for the same species in the coast of France (see King scallop fishery, Baie de Saint-Brieuc, France), there is no S-R relationship (Dobby et al. 2017).

Cappell et al. (2018) reported that the main stock indicator used for the reference points information for this fishery is CPUE data. Target reference point was set as 0.8 of the mean CPUE for the 2008-2015 time series. This period was characterized as highly productive (high CPUE) and stable (low interannual variability) thus consistent or above B_{MSY}. Limit reference point is set as the lowest CPUE value for the same time series, as this value ensures a stock biomass at or above recruitment overfishing (B_{LIM}). In addition, HCRs also use BRPs related to spawning stock biomass (SSB), which are estimated using a model called Virtual Population Analysis (VPA). The logic is the same as for the CPUE-based BRPs, target reference point is set as 0.8 of the mean SSB and limit reference point is set as the lowest SSB value for the 2008-2015 time series. HCRs are determined using both types of BRPs; there are no restrictions when stock biomass (estimated as CPUE, or as SSB) is above the target reference point. When stock biomass is between target and the limit reference points, management actions include (i) increase minimum landing size, (ii) area closures and (iii) restrict fishing days. When it is below the limit reference point, area closures extend. When all reference points are reached a complete closure of the fishery is set.

Sea scallop (*Placopecten magellanicus*) fishery, US Atlantic

The sea scallop is distributed in the Northwest Atlantic, between the Gulf of St. Lawrence (Canada) to Cape Hatteras (North Carolina, USA). In US federal waters, management is based on considering a single stock. This stock, nevertheless, is structured into four main interconnected populations (banks) that form a single metapopulation. Despite being a low genetic structure among banks, dispersion models and genetic evidence suggest that each bank is self-sustaining, with low levels of connectivity between them (connectivity that responds to a model of isolation by distance). Stock assessment is carried out in the two larger banks, which together accumulate 99%of the catches. Annual sampling has been carried since 1979 in both banks using a systematic grid design. Historical data show that there is great variability in recruitment, but that this variability is both temporal and spatial (i.e. added to a regular annual recruitment, there are extraordinary pulses of high recruitment that occur asynchronously in space).

Fishery management (see Anhalzer et al. 2018) is based on B_{MSY} and F_{MSY} reference points, which are calculated analytically (along with their uncertainties) separately for both banks (and then combined for the entire stock). Estimation is done using a specially developed model called Stochastic Yield Model (SYM). This model uses Monte Carlo simulations and combines life history, recruitment and fishing performance data (estimated annually for different areas within each bank), along with stock-recruitment relationships, to construct performance curves and derivate B_{MSY} and F_{MSY}. The target reference point is B_{MSY} and the limit reference point is 0.5 B_{MSY}. HCRs set annual harvest allocations (including an area rotation plan) based on stock biomass projections and the target reference points, assigning catch quotas to maintain the stock at values consistent with these reference points.

Sea scallop (*P. magellanicus*) fishery, Bay of Fundy, Canada

Sea scallop fishery in the Bay of Fundy dates back to 1880. Sea scallop populations are part of a more or less continuous distribution throughout this inshore region. For management purposes, the ground is sub-divided into Scallop Production Areas (SPA) that are assessed separately. However, there is a high interconnection between these areas through larval dispersal/recruitment processes, thus considered an unique metapopulation and

Table 1

Summary of BRPs used for the management of the 10 MSC-certified scallop fisheries in relation to stock-specific characteristics and the available empirical information.

Species	Location	Stock characteristics	Recruitment pattern/S-R relationships	Data availability	BRPs	Methods
King scallop *Pecten maximus*	Baie de Saint Brieuc, France	Self-sustaining single stock, great temporal variability in biomass (cyclic).	Cyclic recruitment (15 years frequency).	Great data availability (>40 years) from fishery dependent and fishery independent sources.	HCRs are not based on BRPs (required as a condition of certification)	N/A
King scallop *P. maximus*	Shetland Island	Limited data about population structure.	No S-R relationship.	Historical fishery catch data, limited data from fisheries-independent surveys.	Target: B_{MSY} (mean annual CPUE), SSB_{MSY} Limit: B_{LIM} (lower observed CPUE), SSB_{LIM}.	Empirical (from CPUE historical data).
Sea scallop *Placopecten magellanicus*	US Atlantic	Metapopulation with connected but self-sustaining populations. Managed as a single stock.	Great temporal and spatial variability.	Great data availability (>40 years) from fishery dependent and fishery independent sources.	Target: B_{MSY} and F_{MSY} Limit: $0.5*B_{MSY}$ Assessed at the two major beds and combined. Updated every 4 years.	Analytic (Monte Carlo simulations).
Sea scallop *P. magellanicus*	Bay of Fundy, Canada	Metapopulation with connected but self-sustaining sub-populations. Great temporal variability in biomass.	Great temporal variability. No S-R relationship.	Great data availability (>100 years) from fishery dependent sources (CPUE). Fishery independent annual stock estimation for each sub-population.	For some sub-populations, Target: B_{MSY} y F_{MSY} Limit: B_{LIM}. Dynamics (annually estimated) For other sub-populations, Target: B_{MSY} (mean CPUE) Limit: B_{LIM} (lower CPUE).	Analytic (Bayesian models), Empirical (from CPUE historical data).
Sea scallop *P. magellanicus*	Off shore Nova Scotia, Canada	Metapopulation with connected but self-sustaining sub-populations. Two main sub-populations	Great temporal variability. One sub-population with S-R relationship.	Historical fishery catch data (CPUE). Fishery independent annual stock estimation for each sub-population.	Target: $0.8*B_{MSY}$ Limit: $0.3*B_{MSY}$.	Analytic (Bayesian models).
Ballot's saucer scallop *Ylistrum balloti*	Abrolhos Island and Midwest, Australia	Single stock structured in sub-populations.	Temperature-dependent S-R relationship.	Fishery independent annual stock estimation for each sub-population.	Target: SB_{MSY} Limit: SB_{LIM}.	Analytic (Stock-Recruitment-Environment models).
Commercial scallop *P. fumatus*	Bass Strait, Australia	Single stock structured in sub-populations, some of them self-sustaining. Great temporal variability in biomass.	Great temporal variability.	Historical fishery catch data. Fishery independent annual stock estimation for each sub-population.	Target: B_{MSY} Limit: B_{LIM}.	Empirical (from CPUE historical data).
Queen scallop *Chlamys opercularis*	Faroe Islands	Single stock, 2 main areas with large concentrations.	Great temporal variability.	No independent stock estimation since 1980 but there is a lot of biological, ecological, distribution and historical fishery catch data (CPUE).	Target: B_{MSY} Limit: B_{LIM}.	Empirical (from CPUE historical data).
Japanese scallop *Mizuhopecten yessoensis*	Japan	Single parent stock outside the cultivation area.	Cultivated stock supports parent stock recruitment	Parent stock is not directly exploted and thus stock status is of secondary importace	HCRs are not based on BRPs	N/A
Patagonian scallop *Zigochlamys patagonica*	Argentina	Metapopulation with connected sub-populations.	Great temporal variability.	Historical fishery catch data. Fishery independent annual stock estimation.	HCRs are not based on BRPs.	N/A.

treated as a single stock unit. Stock is surveyed annually through a combination of random and stratified sampling. These data are then used to model the current and future status of the stock using a Bayesian state-space delay-difference population model. Model is used to estimate population biomass, recruitment, exploitation rate and provide advice on future catch levels (see Meyer and Millar 1999). Recruitment is more influenced by environmental conditions than by spawning stock biomass (there is no S-R relationship). Lack of evidence for a biomass level associated with a MSY makes it problematic for determining MSY-based reference points.

According to Dignan et al. (2018), ad hoc BRPs are established for a subset of the areas. In some areas, BRPs are calculated directly from the biomass and exploitation rate long-term (50 years) model projections. Target reference points are based on the equilibrium biomass and exploitation rate associated with maximum catch (B_{MSY} and F_{MSY} proxies respectivelly), and limit reference points are the lowest biomass in the time series from which a sustained recovery occurred (B_0 proxy). Evaluation is carried out annually, thus, these reference points are dynamic. For other areas, analytical BRPs can not be estimated and empirical BRPs are obtained from historical catch data series (e.g. target reference points based on the average annual catch and limit reference points based on the biomass that generated the lowest historical catch, B_{MSY} and B_{LIM} proxies respectivelly). HCRs are based on these BRPs and set different exploitation rates in accordance to each sub-area stock status and BRPs values. If the stock is above the target reference point, fishing is allowed up to a maximum exploitation rate of 0.15. If it is between the target and limit reference points, fishing is allowed up to an exploitation rate of 0.15 and proportional to the distance from the limit reference point. Finally, if the stock is below the limit reference point, fishing is prohibited.

Sea scallop (*P. magellanicus*) fishery, offshore, Canada

It is very likely that sea scallop populations located in the Canadian Exclusive Economic Zone (EEZ), together with those found in the US EEZ (see Sea scallop fishery, US Atlantic) and with those found in the Bay of Fundy (see Sea scallop fishery, Bay of Fundy, Canada) are, to a certain degree, connected, thus forming a single metapopulation. There is substantial evidence, nevertheless, to consider the Canadian offshore scallop population as more or less isolated and self-sustaining, thus management is based on considering it a separate stock. There are two main banks, Georges Bank and Browns Bank, which are the largest in extinction, have the greatest biomass, and are constantly exploited. In addition to these, there are other marginal banks in which recruitment is sporadic and are infrequently exploited. There is evidence of an S-R relationship only for Georges Bank (McGarvey et al. 1993). Stock annual surveys at the two main banks follow a stratified random design. According to Knapman (2020), stock assessment is performed using a Bayesian state-space modified delay difference assessment model (similar to the one used for stock assessment in Bay of Fundy) that integrates both fishery and survey data. BRPs are determined by fitting the Bayesian stock estimation model for the 1986-2009 time series, where the mean fully-recruited biomass value is used as a B_{MSY} proxy. The limit reference point and the target reference point are set, respectively, as 0.3 B_{MSY} and 0.8 B_{MSY}. There is also a limit reference point that reflects the maximum acceptable removal rate for the stock (F_{MAX} proxy) and is estimated as the exploitation rate that resulted in no biomass change during the period 1981-2007. The HCRs determine that, when the biomass is greater than the target reference point, fishing is permitted at the maximum exploitation rate. When the biomass is between target and limit reference points, the exploitation rate is reduced. Finally, when the biomass is below the limit reference point, a recovery plan, that may or may not include fishing closures, is activated.

Ballot's saucer scallop (*Ylistrum balloti*) fishery, Abrolhos Island and Mid-West, Australia

Ballot's saucer scallop is distributed from Israelite Bay, West Australia to the Southern coast of New South Wales. This species is restricted to sandy bottoms in protected areas, can live 2-3 years and sexual maturation occurs after a year. There is a very strong S-R relationship at the total fishery scale, but little is known about its spatial variability at smaller scales (Chandrapavan et al. 2020). Likewise, reproduction and larval survival appear to be strongly influenced by water temperature. Stock evaluations have been carried out annually in multiple banks since 1997. According to Banks et al. (2021), this fishery is managed with fixed BRPs (based on densities) determined using an S-R model (see Kangas et al. 2021) that includes environmental variables (e.g., water temperature). The objective reference point (750 individuals nautical mile-1) reflects a value above which it is considered that recruitment will only be influenced by environmental factors (B_{MSY} proxy), and the limit reference point (250 individuals nautical mile-1) where it is considered that recruitment would be seriously affected (B_{LIM} proxy). HCRs then take into account the estimated stock status (a single average value) in relation to these reference points. If estimated density values are lower than the limit reference point, the fishery is closed. If values are between limit and target reference points, the season opening date is delayed and the area open to fishing is reduced.

Commercial scallop (*P. fumatus*) fishery, Bass Strait, Australia

Commercial scallops in Bass Strait, South Australia, are found forming relatively discrete banks. Genetic evidence and circulation patterns models suggest that banks are interconnected, except for those located in closed protected bays, which appear to be more isolated and self-sustaining. From a management point of view, these banks are considered local populations with moderate connectivity within a metacommunity (i.e., forming a single stock). Stock assessments are carried out annually using a stratified, random design, but only at areas where high densities of commercial sizes are estimated (i.e., it is not an unbiased estimate of total biomass). According to

Brand-Gardner et al. (2022), the management strategies for this fishery explicitly recognize the existence of strong natural temporal variation in recruitment (and therefore in biomass), thus it is not possible to manage the stock using BRPs based on analytical estimation of B_{MSY}. However, there is a target reference point (B_{MSY} proxy) determined by the maximum value of annual capture in the historical data series. Likewise, a limit reference point (B_{LIM} proxy) was set using biomass data observed for the 1999-2007 period. During this period the fishery was closed because it was considered under recruitment overfishing. HCRs are based on these reference points and on the estimated proportion of commercial size individuals. The banks with a commercial size biomass higher than 1500 tons are open to fishing, and the total allowable catch is calculated based on the excess biomass above the limit reference point.

Queen scallop (*Chlamys opercularis*) fishery, Faroe Islands

The queen scallop is a species that is commonly exploited in the Northeastern Atlantic and the Mediterranean. At the Faroese shelf, there are two main areas with high concentrations, which are considered a single stock. According to Bostrom et al. (2022), there have been no stock assessments since the 1980s (where data showed high biomass values), so management currently uses empirical BRPs based on CPUE data corrected by standardization models. Using the historical CPUE data, a target (B_{MSY} proxy) reference point (i.e., 1.5 ton hour-1) and a limit (B_{LIM} proxy) reference point (i.e., 1 ton hour-1) were set. HCRs are based on these values; Areas in where the CPUE is higher than the target reference point can continue to be fished, areas in where the CPUE is between the two values should be avoided, and areas in where the CPUE is below the limit reference point are closed for at least two years. Despite the existence of these empirical reference poits, the RBF were used during the MSC initial assesment (2022) to score stock status because no stock status relative to reference points is available for target species.

Japanese scallop (*Mizuhopecten yessoensis*) fishery, Japan

The Japanese scallop is a cold-water species distributed in subarctic coastal waters of the eastern Pacific, especially off the coast of Japan. In this fishery, seeds are collected in the wild on hanging spat collectors and are then grown on using suspended nets or cultivated on the seabed to later be fished. Since the fishery is based on a system that does not affect the parent stock, which is located outside the cultured area, there are no BRPs (see Akroyd and Blyth-Skyrme 2023). During the MSC initial assesment (2010), the RBF were used to score stock status and HCRs because there are no biologically based reference points available for the stock. After the second re-assesment (2018), nevertheless, it was determined that it is not required to score Principle 1 because there is no evidence that the fishery negatively impacts the parent stock.

Patagonian scallop (*Zygochlamys patagonica*) fishery, Argentina

The Patagonian scallop is distributed from Southeast Pacific to Southwest Atlantic and Antarctic inhabiting soft bottom,mainly muddy-sandy substrates. In the Argentinean continental shelf it is structured as a metapopulation with discrete beds along the shelf break, interconnected by larval drift. There is a latitudinal gradient in sizes and recruitment shows strong temporal and moderate spatial variability. Stock is assessed annually with a systematic sampling design (although some beds are sampled with a simple random design). HCRs are not based on BRPs. Instead, a TAC is calculated for each bed as 40%of the estimated commercial biomass lowest confidence limit, after the exclusion of areas where the two conditions are not met: (i) density more than 10t km-2; and (b) the proportion of individuals lesser than 55 mm is less than 0.5 (Morsan et al. 2023).

MSC-certified fisheries targeting other (mostly) sessile organisms

In general, MSC-certified fisheries targeting other (mostly) sessile organisms show a similar pattern than the observed for scallop fisheries, there is a great variability in the used BRPs.

The US Atlantic surfclam (*Spisula solidissima*) and the Ocean quahog (*Arctica islandica*) fisheries, in the east coast of the US, for example (see DeAlteris and Allen 2016), use BRPs based on fractions of the exploitable biomass observed in very good years (B_{MSY} proxies), or available biomass before the fishery begins (B_0 proxies). For the surfclam, the target reference point is 0.5 B_{MSY} and the limit reference point is 0.25 B_{MSY}. The quota (TAC) is determined based on the stock estimated values in relation to these reference points. The management of the Striped clam (*Chamelea gallina*) fishery in Venice, on the other hand, is based on B_{MSY} and F_{MSY} analytically estimated using a Bayesian surplus production model (see Kiseleva et al. 2024). The Arctic surf clam (*Mactromeris polynyma*) fishery in eastern Canada (see Knapman et al. 2023) has BRPs established as 80%(target) and 40%(limit) of the B_{MSY}, which is calculated using yield-per-recruit and the average annual recruitment values. In Denmark (see Cappell and Ennis 2023), the razor clam (*Ensis directus*) fishery, an introduced species in the North Sea, uses a fixed limit for the TAC, which cannot exceed 20%of the estimated adult stock weight. While in the United Kingdom (Jones and Caveen 2023), the Cockle (*Cerastoderma edule*) and Japanese carpet shell (*Ruditapes philippinarum*) fisheries do not use BRPs as stocks are considered to be at (or above) B_{MSY} as long as no drop in CPUE values are observed.

In the silver lipped pearl oyster (*Pinctada maxima*) fishery in Western Australia, oysters are gathered by hand. HCRs set TAC using reference points based on Standardised CPUE (SCPUE) as well as a predictive model that allows estimating a limit SCPUE that drives to recruitment failure. This level is close to the lowest value (recorded in 1981), and has therefore been empirically shown not to lead to recruitment impairment. Range of target reference point is set encompassing the range of catch rates observed since about 1992 (Daume et al. 2023). In Denmark, the oyster (*Ostrea edulis*) fishery does not use BRPs. This is justified because there is a large protected population of oysters in the shallow subtidal and intertidal which subsidize recruitment to the waters where fishing is permitted and because the fluctuations in oyster stock biomass are environmentally driven (Andrews et al. 2017, Addison and Grieve 2021). A similar situation occurs in the Netherlands with the fishery targeting the invasive Pacific oyster (*Crassostrea gigas*) and the native oyster (*O. edulis*). Lack of BRPs is justified since, for *C. gigas*, oyster are removed from an expanding non-native population, and for *O. edulis*, high mortality is expected (due to a protozoan parasite), so these are removed prior to expected mortality but after spawning (Sieben et al. 2018). Pacific oysters (*C. gigas*) catch and grow in the Seto Inland Sea also do not use BRPs since this fishery is based on collecting the seeds with spat collectors and raising them on ropes. Rope growing-activities will increase the local oyster stock biomass (Seip-Markensteijn and Tamura 2019).

The blue mussel (*Mitilus edilus*) fishery in Denmark does not use BRPs since it is based on fishing the seeds from the subtidal (where the beds are ephemeral and highly variable) and raising them in pools (Stern-Pirlot and Grieve 2022), or gathering larvae using spat collectors and raising them on ropes (Andrews and Hønneland 2022, Andrews and Maar 2022). Fishery is considered to have no effect (or even have a positive effect) on the natural stock. A similar situation is observed for blue mussel fisheries in Germany (Collinson et al. 2018), the Netherlands (Gascoigne et al. 2016, 2021), Sweden (Hønneland and Seip 2019) and Ireland (Dignan et al. 2018, Donnelly and Dignan 2019). In Denmark however, there is another fishery that operates by direct fishing on natural subtidal banks, but this fishery is also not managed by BRPs as the effect on the stock is considered to be very low (Addison and Grieve 2021).

The whelk (*Buccinum undatum*) fishery in France has BRPs based on historical CPUE data; limit reference point is set as the lower confidence interval for the minimum value of the observed time series of LPUE from which the stock had demonstrably recovered (B_{LIM} proxy) and target reference point is set as 2 times this value (Wilson et al. 2023). Abalone (*Haliotis laevigata*, *H. conicopora* and *H. roei*) fisheries in Australia have BRPs based in B_{MSY} fractions; B_{MSY} estimations are analytically derived from specific models (Daume et al. 2022).

Reference points used by International Council for the Exploration of the Sea (ICES) for advice

ICES provides scientific advice to government and international regulatory bodies that manage fisheries in the North Atlantic Ocean and adjacent seas. ICES classifies stocks into six main categories on the basis of available knowledge: (1) Stocks with full analytical assessments and forecasts; (2) Stocks with analytical assessments and forecasts that are (for a variety of reasons) only treated qualitatively as well as stocks with surplus production models; (3) Stocks for which survey, trends-based assessment, or other indices and life history information are available that provide reliable indications of trends in stock metrics; (4) Stocks for which a reliable time-series of catch can be used to approximate MSY; (5) Stocks for which either only data on landings or a short time-series of catch are available; and (6) Stocks for which there are negligible landings and stocks caught in minor amounts as bycatch (ICES 2012). For categories 1 and 2, ICES advises for the use of analytical reference points, mainly based in B_{MSY} and B_{LIM}. For categories 3 and 4, as analytical assessment is not possible, estimation of B_{MSY} and B_{LIM} proxies from reliable time-series of catch, abundance or biomass is advised. Finally, for categories 5 and 6 only risk assessments through Productivity and Susceptibility Analysis (PSA) can be performed. King scallop fisheries from the English coast, for instance, are suggested to have a category 1 stock and, under ICES advice, HCRs are based on F35%VSpR, the fishing mortality which generates 35%of the virgin spawning potential (Lawler et al. 2022). The Isle of Man king scallop fishery, in contrast, has a category 3 stock and its Long-term Management Plan aims to incorporate robust, evidence-based BRPs (e.g., B_{MSY} and B_{LIM} proxies from long-term CPUE data; Bloor 2021). Results from the present review suggest that MSC-certified scallop fisheries have BRPs consistent with ICES advice.

DISCUSSION

Setting reference points is a critical step in the development of fisheries harvest strategies, but choosing appropriate BRPs among the many candidates is not an easy task. Ideally, choosing the most accurate BRPs requires information on the biology of the species, larval dispersal, source-sink dynamics, and oceanographic conditions, but this information is not always available (ICES 2020). In practice, thus, BRPs are usually chosen on the basis of the best available knowledge, and can be eventually replaced as information accumulates.

Despite there are some scallop fisheries with analytically obtained BRPs, analytical standard fixed reference points (e.g., B_{MSY} and B_0) may be not useful for stocks with highly variable and cyclic recruitment, or when there is no evidence of a S-R relationship. Most scallop fisheries, as well as other fisheries targeting sedentary benthic organisms, have stocks with these characteristics, or they lack the necesary information, thus empirical estimation of B_{MSY} and B_{MSY} proxies from reliable time-series of catch, abundance or biomass are oftenly used. This pattern is consistent with ICES advice in relation to stock categories (ICES 2012).

Population densities, growth, recruitment, and exploitation, are not necessarily spatially uniform, and development of reference points and HCRs may require understanding of the spatial variation to include spatial considerations if necessary (Smith et al. 2017). Indeed, recent improvements in the ability to estimate spatially structured biological parameters and link them to hydrodynamic models as well as map the resources and fleet movement patterns now allow the development of spatially variable BRPs (Smith and Rago 2004). Finally, stock variability in life history, recruitment, and historical exploitation not only occurs over space but also over time, as biological parameters usually change when the environment changes (e.g. year to year changes in food availability and predator densities affect mortality and growth, changes in oceanographic conditions can lead to sporadic large recruitments; Campos et al. 2023). Thus, fixed reference points, referring to an equilibrium or average situation, may not guarantee stock stability and the possibility of dynamic BRPs should be considered by incorporating eventual changes in the life history parameters to analytical models or by using mobile frames for time-series data.

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