Ciencia Pesquera (2023) 31(1): 115-122

Addressing spatial management questions through dynamic bioeconomic modelling of fisheries targeting sedentary species: A brief review

Aspectos de la gestión espacial a través de modelos bioeconómicos dinámicos de pesquerías dirigidas a especies sedentarias: Una breve revision

Juan Carlos Seijo[*] *& Germán Ponce Díaz*[**]

Abstract

This manuscript reviews the scientific contributions by Professor John F. Caddy for properly understanding and modelling the heterogeneity over space and time of resource abundance and spatial behavior of fishing intensity in fisheries targeting sedentary species. As spatial data on patch distribution of stocks become available for low or null mobility sedentary resources, responsible management requires relaxing the dynamic pool assumptions. It also involves proper understanding of fisher behavior driving the spatial allocation of fishing intensity over time. As pointed out by Caddy (1975), Seijo & Caddy (2008) and Anderson & Seijo (2010), the Schaefer-Gordon and Beverton-Holt models are based on dynamic pool assumptions, which establish that: *i*) the resource is homogeneously distributed in space; *ii*) ages are perfectly mixed; and either *iii*) fishing effort is applied uniformly over the range of resource distribution, or *iv*) after fishing effort has been applied, the resource is able to redistribute itself according to *i*) and *ii*). For sedentary and low mobility resources, models based on dynamic pool assumptions are inadequate and may result in serious model error for fisheries targeting sedentary species of bivalve molluscs, gastropods, and echinoderms. This type of resources exhibits stock patchiness with heterogeneous distribution of patch size, density, and age structure. As a result, fishers respond by allocating their fishing intensity over space and time by considering the heterogeneous stock abundance, the distance and associated costs and corresponding quasi-profits of the variable costs of fishing in alternative sites. As pointed out by Caddy (1975) the main consequence of this spatial heterogeneity is that under dynamic pool assumptions the productive potential of the stock is overestimated, increasing the risk of over-exploitation and collapse of the fishery targeting sedentary or low mobility species. This manuscript summarises the fisheries science contributions of the first dynamic age-structured spatial model, published in by John F. Caddy in 1975. Also, reviews how this model evolved into a geographic spatial bioeconomic model for fisheries targeting sedentary species to answer questions such as: How to model the age-structured spatial dynamics of sedentary species recruiting in patches of random size and location? How to determine the seasonal and long-run spatial dynamics of stocks and the corresponding fishing intensity targeting sedentary species over space and time? Which is the bioeconomic optimal rotating harvest strategy for sedentary species with heterogeneous renewability capacity? Which are the dynamic biomass and resource rent effects of alternative states of nature of uncertain biologic and economic parameters? What is the bioeconomic effect of port location in relation source and sink areas of metapopulations recruiting in patches over space and time? What is the bioeconomic effect of location of area closures (MPA's) with identifiable source and sink areas of targeted stocks of sedentary species? This manuscript also identifies research and management questions of a high value species targeted by a small-scale fleet of Mexico which could consider spatial analysis approaches to aid decision making for stock recovery of sedentary highly vulnerable stocks.

Keywords: Spatial, patch density, heterogeneous distribution, fishing intensity, sedentary species, metapopulations, source, sink, spatial management, bio-economics.

---

[*] Universidad Marista de Mérida.

[**] Instituto Politécnico Nacional-Centro Interdisciplinario de Ciencias Marinas

Resumen

El presente trabajo revisa las contribuciones científicas del profesor John F. Caddy para comprender y modelar de forma adecuada la heterogeneidad en el espacio y el tiempo de la abundancia de recursos y el comportamiento espacial de la intensidad de pesca en las pesquerías dirigidas a especies sedentarias. A medida que se dispone de datos espaciales acerca de la distribución en parches de las poblaciones de recursos sedentarios, de movilidad baja o nula, el manejo responsable requiere relajar los supuestos de agregamiento dinámico. También implica una comprensión adecuada del comportamiento de los pescadores hacia la búsqueda espacial y la intensidad de pesca a lo largo del tiempo. Como se destacó por Caddy (1975), Seijo y Caddy (2008) y Anderson y Seijo (2010), los modelos Schaefer-Gordon y Beverton y Holt, se basan en un grupo de suposiciones de agregamiento dinámico que establecen que: *i)* el recurso está homogéneamente distribuido en el espacio; *ii)* las edades están perfectamente mezcladas; y también *iii)* el esfuerzo de pesca se aplica de manera uniforme en el rango de distribución del recurso, o *iv)* después de que el esfuerzo de pesca se aplicó, el recurso es capaz de redistribuirse de acuerdo con *i)* y *ii)*. Cabe señalar que para los recursos sedentarios y de baja movilidad, los modelos basados en supuestos de agregamiento dinámico son inadecuados y pueden dar lugar a un grave error de modelo para las pesquerías dirigidas a especies sedentarias de moluscos bivalvos, gasterópodos y equinodermos. Este tipo de recurso muestra stocks en parches con una distribución heterogénea del tamaño del parche y estructura de sus edades. Como resultado, los pescadores responden asignando su intensidad de pesca en el espacio y tiempo, considerando la abundancia heterogénea del *stock*, la distancia y los costos asociados y las *cuasi*-utilidades de los costos variables, es decir, utilidades que quedan después de cubrir los costos variables de la pesca en sitios alternativos. Como señaló Caddy (1975), la principal consecuencia de esta heterogeneidad espacial es que, conforme a los supuestos de agregamiento dinámico, se sobrestima el potencial productivo del *stock*, lo que aumenta el riesgo de sobreexplotación y colapso de la pesquería dirigida a especies sedentarias o de baja movilidad. Este manuscrito resume las contribuciones de la ciencia pesquera del primer modelo espacial dinámico estructurado por edad, publicado por John F. Caddy en 1975. También revisa cómo este modelo evolucionó a un modelo bioeconómico espacial geográfico para pesquerías de especies sedentarias, para responder a preguntas como: ¿Cómo modelar la dinámica espacial estructurada por edad del reclutamiento de especies sedentarias en parches de tamaño y ubicación aleatorios? ¿Cómo determinar la dinámica espacial estacional y de largo plazo de las poblaciones, así como la correspondiente intensidad de pesca dirigida a especies sedentarias en el espacio y el tiempo? ¿Cuál es la estrategia bioeconómica óptima de cosecha rotativa para especies sedentarias con capacidad de renovación heterogénea? ¿Cuáles son los efectos dinámicos de la biomasa y la renta de recursos de estados alternativos de la naturaleza de parámetros biológicos y económicos inciertos? ¿Cuál es el efecto bioeconómico de la ubicación del puerto en relación con las áreas de fuente y sumidero de las metapoblaciones que se reclutan en parches en el espacio y el tiempo? ¿Cuál es el efecto bioeconómico de la ubicación de áreas marinas protegidas (*AMP*) con áreas identificables fuente y sumidero de poblaciones de especies sedentarias? Este manuscrito también identifica preguntas de investigación y manejo de una especie objetivo de alto valor de las flotas de pequeña escala de México que podrían considerar enfoques de análisis espacial, para ayudar a la toma de decisiones sobre la recuperación de poblaciones sedentarias altamente vulnerables.

Palabras clave: espacial, densidad por parches, distribución heterogénea, mortalidad por pesca, especies sedentarias, metapoblaciones, fuente, sumidero, gestión espacial, bioeconomía

Introduction

Forty-seven years ago, John F. Caddy built and published the first yield per recruit age structured spatial model (Caddy 1975), called YRAREA, of geographically contiguous unit areas, and the realism of age structure and applied it to the Georges Bank scallop fishery. The model generates a virgin stock by stochastic patch distribution of recruitment using the bi-variate normal distribution to distribute individuals over space once the patch centre has been randomly selected. Spatially distributed fishing intensity is represented as a function of spatially heterogeneous catch per unit of effort. Almost 20 years after this contribution, Seijo, Caddy & Euan developed a bioeconomic simulation package to model the space-time distribution of sedentary and low mobility stocks, and the corresponding spatial dynamics of fishing intensity (Seijo *et al.* 1994). Included in the software package of this publication, CHART models the short and long-run spatial dynamics of sedentary and low mobility demersal resources because of interacting biologic, economic and geographic characteristics. It is an age structured spatial and dynamic bioeconomic model that estimates distance and transfer costs from different ports of origin to alternative fishing sites. It models seasonality of recruitment and fishing intensity using the distributed delay model. Allocates seasonal effort over space and time using a function considering the quasi-rent of the variable's costs obtained from different sites in previous trip, the probability of finding the resource in profitable levels in alternative sites, and the friction of distance to account for the non-monetary costs of fishing.

Afterwards, Caddy & Seijo (1998) explored the effect of alternative rotating harvest strategies for harvesting of sedentary species with different life cycles as identified with alternative sets of combined natural mortality M and curvature parameter *k* of von Bertalanffy individual growth function. A spatial age structured bioeconomic model was built to explore alternative sizes of closed areas and the bioeconomic optimum rotating period. In 1999, professor Caddy & Carocci (1999) illustrate some practical Geographical Information System (GIS) applications for aiding fishery managers and coastal area planners in analysing the likely interactions of ports, inshore fleets, and local non-migratory inshore stocks, and in providing a flexible modelling framework for decision making on fishery development and zoning issues. Afterwards, Anderson (2002) developed a discrete bioeconomic model for two patches with source-sink configuration and developed the corresponding analytical solution for the open access bioeconomic equilibrium for both, density dependent migration and source-sink migration. Charles & Reed (1985) developed a bioeconomic model to determine optimal harvest allocation between "offshore "and "inshore" fleets exploiting a single fish stock in sequential fisheries. The socially optimal policy for maximizing total discounted rent is determined in terms of optimal escapement levels in each fishery. Whether exclusion or coexistence of the two fleets occurs under open access and under optimal management is found to depend primarily on inshore/offshore price and cost ratios, together with biological parameters related to the age structure of the fish stock. The authors discuss how fishery regulations, such as separate landings taxes imposed on each fleet, can be used to jointly optimize open-access exploitation in sequential fisheries.

Sumaila (1998) developed a dynamic bioeconomic model with the objective of assessing protected marine reserves as fisheries management tools. Two key results emerge from the study. First, establishment of marine reserves are bio-economically beneficial when net transfer rates are "reasonably" high and reserve sizes are large: large reserves provide good protection for the stock in the face of the shock, while high transfer rates make the protected fish available for harvesting after the shock has occurred. Further, optimally chosen reserve size when net transfer rates are high, also mitigates against biological losses. Second, when net transfer rates are low, the establishment of marine reserves does not mitigate against losses in the discounted economic rent, while they tend to be efficient in mitigating against biological losses.

Hannesson (1998, 2002) investigated what would happen to fishing outside the marine reserve and to the stock size in the entire area as a result of establishing a marine reserve. Three regimes were compared: *i)* open access to the entire area, *ii)* open access to the area outside the marine reserve, and *iii)* optimum fishing in the entire area. Two models are used: *i)* a continuous-time model, and *ii)* a discrete-time model, both using the logistic growth equation. Both models were deterministic equilibrium models. The conservation effect of a marine reserve was shown to be critically dependent on the size of the marine reserve and the migration rate of fish. The author also found that a marine reserve will tend to increase fishing costs.

A bioeconomic model of a harvesting industry operating over a heterogeneous environment comprised of discrete biological populations interconnected by dispersal processes, was developed by Sanchirico & Wilen (2001). The model provides a framework from which one can investigate factors that contribute to the evolution of resource exploitation patterns over space and time. For example, we find that exploitation patterns are driven by biological and fleet dispersal and biological and economic heterogeneity. Seijo, Perez & Caddy (2004) developed a spatial bioeconomic model based on the negative binomial distribution to represent patches that vary in in size, density, and age structure over time. The model incorporates decision matrices and different levels of risk aversion in resource management to account for the uncertainty associated with alternative spatially disaggregated fishing strategies. Smith & Wilen (2004) added another layer of behavioral realism to the bio-economics of marine reserves by endogenizing fisher home port choices with a partial adjustment share model. Estimated with Seemingly Unrelated Regression over monthly data, this approach allows simulation of both short- and long-run behavioral response to changes induced by marine reserve formation. The findings cast further doubt on the notion that marine reserves generate long-run harvest benefits.

Seijo & Caddy (2008) developed a dynamic age-structured spatial model using the negative binomial probability density function to distribute recruitment patches over space and time. The authors explored the effect of alternative location of marine protected areas (MPA's) and its bioeconomic effect in metapopulations of sedentary or low mobility species with source-sink configuration. The effect considered the alternative locations of ports of origin of a fleet targeting the sedentary species. Short-run spatial allocation of fishing intensity and long-run effort dynamics is also built-in this spatial model.

Anderson (2002) analytically disaggregated the spatial cost function of a fishing trip into two components: *i) steaming costs* for going to geographically heterogeneous fishing sites, and *ii)* the *fishing costs* involved in those sites.

More recently, González-Durán *et al.* (2018) applied the spatial model developed by Seijo & Caddy (2008) to calculate the Allee effect in a fishery targeting the population of Sea Cucumber (*Badionotus* spp.) of the Yucatan shelf. The difficulties and complexities of modelling and management of a diversity of species are acknowledged in Caddy & Seijo (2005).

Methods

In this section we summarize the spatial approach to modelling fisheries targeting sedentary or low mobility species for answering a set of research questions identified over time in collaboration with John F. Caddy. *Table 1* shows the research question, modelling approach, research findings and the corresponding reference:

Table 1.
Research and management questions addressed by J.F. Caddy in cooperation with Mexican scientists

Research question	*Modelling approach*	*Research Findings*	*Reference*
¿How to model the age-structured spatial dynamics of sedentary species recruiting in patches of random size, density, and location?	Dynamic and stochastic age structure spatial model for sedentary species.	Spatial yield per recruit per unit area. Spatial distribution of biomass of a bivalve species. Allocation of fishing intensity as a function of spatial resource abundance (CPUE over space).	Caddy (1975)
How to determine the seasonal and long-run spatial dynamics of stocks and the corresponding fishing intensity targeting sedentary species over space and time?	Dynamic and stochastic age structured bioeconomic model with seasonality using the distributed delay model to geographically distribute recruits of sedentary species. Spatial distribution of fishing intesity.	The distribution of quasi-profits of the variable's costs, the probability of finding target species in in profitable levels, and the friction of distance (non-monetary costs of fishing) in alternative sites, determine the distribution of fishing intensity over space and time.	Seijo *et al.* (1994)
Which is the bioeconomic optimal rotating harvest strategy for sedentary species with heterogeneous renewability capacity?	Spatial age structured bioeconomic model to determine optimal rotating harvest for species with heterogeneous renewability capacities.	For different groups of species, alternative combinations of natural mortality (M) and curvature parameter *k* of the Von Bertalanfy growth function, bioeconomic optimal rotating harvest strategies of sedentary species are calculated.	Caddy & Seijo (1998)

Continued Table 1

Research question	*Modelling approach*	*Research Findings*	*Reference*
Which is dynamic biomass and resource rent effect of alternative states of nature of uncertain biologic and economic parameters?	Uncertainty is included in parameter estimates used in a simple age structured spatial and dynamic model using the negative binomial distribution for representing heterogeneity of stock density and resource rent over time. Fishery uncertainty is included through decision matrices.	This simple spatial model calculates heterogeneity of stock abundance, yield and resource rent using the negative binomial probability distribution to calculate the biomass and resource rent over time. Decision matrices are calculated to consider the effect of performance variables under possible states of nature and alternative fishery management decisions.	Seijo *et al.* (2004)
What is the bioeconomic effect of port location in relation source and sink areas of metapopulations?	A spatial dynamic age structured bioeconomic model to calculate short and long run dynamics of biomass and fishing intensity over space to simulate the effect of fleet port location on metapopulations of sedentary species with source-sink configuration.	Port location near source area without an MPA protecting it is a recipe for stock exhaustion.	Seijo & Caddy (2008)
What is the bioeconomic effect of location of fishing closures (MPA's) in metapopulations with identifiable source and sink areas of targeted stocks of sedentary species?	The above mentioned dynamic bioeconomic spatial model was expanded to include Anderson (2002) spatial cost equation which disaggregated the cost function into steaming and fishing costs for a trip from considers the effect of alternative locations and size of MPA's.	Location of MPA in sink area even with limited entry increase the probability of overexploitation because fishing intensity increases over the remaining space which also includes the source area. This occurs because fishing density (effort per unit area) increases in the fishing access area.	Seijo & Caddy (2008)

Concerning the complexities of managing species with different degrees of mobility, the corresponding high exclusion costs, the costs of effective monitoring, enforcement, and compliance, and how these could be distributed among resource users and governments are discussed in Caddy & Seijo (2005).

Considerations for potential application of spatial modelling to answer management questions in fisheries targeting high value sedentary stocks in México are illustrated for the abalone fishery of México.

Results and Discussion

Fishery context

The abalone fishery in Mexico was established on western coast of the Baja California peninsula towards the end of the 19th century with the exploitation of abalone by the Asian population (Chinese and Japanese) residing in California, USA (Estes 1977, Crespo-Guerrero & Jiménez-Pelcastre 2018). Later, around the 1930s, Mexican fishermen began to catch abalone and other fishing resources around Bahía Tortugas, Punta Eugenia, Malarrimo and in other nearby towns such as Bahía Asunción and Punta Abreojos, Baja California Sur, where years later, several cooperative societies were founded in this important fishing region (Arce Leree & Liera Villavicencio 1998).

According to León Carballo & Muciño Díaz (1996), the abalone fishery has represented one of the most important activities that take place on western coast of the Baja California peninsula, from the border with the United States of America to Isla Margarita in Baja California Sur. This sedentary group of species (green abalone *Haliotis fulgens*, yellow abalone *Haliotis corrugate*, black abalone *Haliotis cracherodii*, red abalone *Haliotis rufescens*, and Chinese abalone *Haliotis sorenseni*), recruit in patches with heterogeneous spatial distribution and density (Guzman del Próo *et al*. 2013, Guzmán del Próo & Borges 2016). The species most exploited by diving is the green abalone in percentages greater than 75%, followed by the yellow one with 18 to 23% and the remaining 2% distributed among the other species (León Carballo & Muciño Díaz 1996). Abalone capture is carried out using hookah diving and is undertaken by fishing cooperatives that have fishing concessions. The coastline of the western coast of the Baja California peninsula has been divided into four large fishing zones (DOF 1993, 21/12/93) where there are different opening and closing dates of fishing seasons.

Since the end of the 1990s, the National Fisheries Institute (INAPESCA) has implemented a regional program for qualitative and quantitative stock assessments, and in this way estimate potential catch volumes (León Carballo & Muciño Díaz 1996). Abalone stock assessments have been based since 1996 on a biomass dynamic model adjusting the biomasses predicted by the model to the biomasses estimated directly. This analysis is the basis for quota allocation using the management scheme applied from 1996-1997. Additionally, the minimum catch sizes and seasonal closures for concession areas and permits to cooperatives are considered (DOF 1993, 21/12/93, Anonymous 2006). Some authors have reported effects of climate variability on the growth and development of these species in the abalone production area in Mexico, among others Ponce-Díaz *et al.* (2004) and Vargas *et al.* (2021).

The fishing cooperatives have a concession for abalone fishing, as is the case of the Bahía Tortugas Fishing Production Cooperative, S.C.L. (DOF 1992, 16/10/1992), where the concession area for the fishing of various species (abalone, lobster, snail, sea cucumber, macroalgae and fish, among others) has been allocated. The quota of abalone assigned to the capture by the fishing authority is related to the fishing area and banks where the mollusk is distributed, so in general there is regulation for this capture between fishing banks, but greater detail is needed within the abalone bed itself (*Pers. comm*. Mario Ramade, FEDECOOP Baja California).

The abalone fishery for a long time generated important catches that reported an average of 3 000 tons per year, including a maximum of 6 000 in the 1960s, to later present a gradual and sustained decrease until reporting very low productions (400 t) in the 1990s (Ponce-Díaz *et al*. 1998). The price of the final product (abalone cans) is an important modulator of the fishing activity at the end of the 1990s was as high as $2 200 US per box of 48 cans, which meant fishery export revenues in the order 36 million US dollars. This resource is exploited by fishing cooperatives made up of around 1 300 members who catch abalone and other species such as lobster, snail, and scale, among others (Ponce-Díaz *et al*. 1998).

In the central region of the western coast of the Baja California peninsula, the average catches of fresh abalone meat have remained in the period 2000-2015 at 460 tons, that is, 15% of the average catches of the 1960s. Due to this, the fishery is considered in deterioration (DOF 2018, 06/11/2018).

Fishery status

Since 2017, the abalone fishery of La Bocana, BCS, was assessed as highly overexploited and a moratorium was put in place from that year until today. Recently, Vargas-López *et al*. (2021) calculated growth functions for *Haliotis fulgens* and *Haliotis corrugata* considering environmental variability affecting them.

Questions to guide decision-making

Some questions identified for this fishery which could be addressed applying John F. Caddy theoretical contributions include the following: Which is the moratoria timeline required to recover stocks of overexploited abalone fisheries? Is there available information for stock assessment, modelling and management of a fishery targeting abalone that recruits in patches of different size and density and heterogeneous spatial distribution? Which is the bioeconomic optimal rotating harvest strategy and corresponding exploitation rates for abalone species with heterogeneous resilience capacities?

References

Anderson LG. 2002a. A Bioeconomic Analysis of Marine Reserves. *Natural Resource Modelling* 15(3): 311-334. DOI: 10.1111/j.1939-7445.2002.tb00092.x

Anderson LG. 2002b. A comparison of the utilization of stocks with patchy distribution and migration under open access and marine reserves: an extended analysis. *Marine Resource Economics* 17(4): 269-289.

Arce Leree R, FS Liera Villavicencio. 1998. *Punta Abreojos 1948-1998*. Ensenada, B.C., México. 104p.

Caddy JF. 1975. Spatial model for an exploited shellfish population, and its application to the Georges Bank scallop fishery. *Journal of the Fisheries Research Board of Canada* 32(8): 1305-1328. DOI: 10.1139/f75-152

Caddy JF, JC Seijo. 1998. Application of a spatial model to explore rotating harvest strategies for sedentary species. *Canadian Special Publication of Fisheries and Aquatic Sciences* 125: 359-365.

Caddy JF, F Carocci. 1999. The spatial allocation of fishing intensity by port-based inshore fleet: A GIS application*. ICES Journal of Marine Science* 56(3): 388-403. DOI: 10.1006/jmsc.1999.0477

Caddy JF, JC Seijo. 2005. This is more difficult than we thought! - the responsibility of scientists, managers, and stakeholders to mitigate the unsustainability of marine fisheries. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360(1453): 59-75. DOI: 10.1098/rstb.2004.1567

Charles AT, WJ Reed. 1985. A bioeconomic analysis of sequential fisheries: competition, coexistence, and optimal harvest allocation between inshore and offshore fleets. *Canadian Journal of Fisheries and Aquatic Sciences* 42(5): 952-962. DOI: 10.1139/f85-120

Crespo-Guerrero JM, A Jiménez-Pelcastre. 2018. Orígenes y procesos territoriales del cooperativismo pesquero en la zona Pacífico Norte de Baja California Sur, México, 1850-1976. *América Latina en la Historia Económica* 25(1): 196-238. DOI: 10.18232/alhe.v25i1.841

DOF. 1992. Concesión que otorga el Poder Ejecutivo a través de la Secretaría de Pesca a la Sociedad Cooperativa de Producción Pesquera “Bahía Tortugas”, S.C.L. *Diario Oficial de la Federación*. México. 16 de octubre de 1992.

DOF. 1993. Norma Oficial Mexicana 005-PESC-1993, para regular el aprovechamiento de las poblaciones de las distintas especies de abulón en aguas de jurisdicción federal de la Península de Baja California. *Diario Oficial de la Federación*. México. 21 de diciembre de 1993.

DOF. 2018. Acuerdo por el que se da a conocer la actualización de la Carta Nacional Pesquera. *Diario Oficial de la Federación*. México. 11 de junio de 2018.

Estes D. 1977. Kondo Masaharu and the best of all fishermen. *The Journal of San Diego History* 23(3): 1-19.

González-Durán E, A Hernández-Flores, JC Seijo, A Cuevas-Jiménez, A Moreno-Enriquez. 2018. Bioeconomics of the Allee effect in fisheries targeting sedentary resources. *ICES Journal of Marine Science* 75(4): 1362-1373. DOI: 10.1093/icesjms/fsy018

Guzmán del Próo SA, JM Borges Souza. 2016. Distribución espacial de abulón (*Haliotis fulgens y H. corrugata*) y su variación en el tiempo; implicaciones para su manejo. *Oceánides* 31(2): 35-44. DOI: 10.37543/oceanides.v31i2.184

Guzmán del Próo SA, P del Monte-Luna, J Carrillo-Laguna. 2013. Reclutamiento del abulón azul (*Haliotis fulgens*) en Baja California, México, y su relación con la temperatura del mar. *Interciencia* 38(8): 609-614. DOI: 0378-1844/13/08/609-06

Hannesson R. 1998. Marine reserves: What do they accomplish? *Marine Resources Economics* 13(3): 159-170. DOI: 10.1086/mre.13.3.42629231

Hannesson R. 2002. The economics of marine reserves. *Natural Resource Modeling* 15(3): 273-290. DOI: 10.1111/j.1939-7445.2002.tb00090.x

León Carballo G, M Muciño Díaz. 1996. Pesquería de abulón. *In*: M Casas-Valdéz, G Ponce Díaz (eds.). *Estudio del Potencial Pesquero y Acuícola de Baja California Sur*. FAO/SEMARNAP/Instituto Nacional de la Pesca/CONACYT/Gobierno de Baja California Sur. México. 1: 15-41.

Ponce-Díaz G, A Vega-Velázquez, M Ramade-Villanueva, G León-Carballo, R Franco-Santiago. 1998. Características socioeconómicas de la pesquería de abulón en la costa oeste de la península de Baja California, México. *Revista de Investigación de Mariscos* 17(3): 853-857.

Ponce-Díaz G, E Serviere-Zaragoza, IS Racotta, T Reynoso-Granados, A Mazariegos-Villarreal, P Monsalvo-Spenser, D Lluch-Belda. 2004. Growth and tissue biochemical composition of *Haliotis fulgens* at elevated temperatures in Baja California under two dried Brown algal diets. *Journal of Shellfish Research* 23(4): 1051-1058.

Sanchirico JN, J Wilen. 2001. Dynamics of spatial exploitation: A metapopulation approach. *Natural Resource Modeling* 14(3): 391-418. DOI: 10.1111/j.1939-7445.2001.tb00064.x

Smith MD, J Wilen. 2004. Marine Reserves with Endogenous Ports: Empirical Bio-economics of the California Sea Urchin Fishery. *Marine Research Economy* 19(1): 85-112.

Seijo JC, JF Caddy. 2008. Port location for inshore fleets affects the sustainability of coastal source-sink resources: implications for spatial management of metapopulations. *Fisheries Research* 91(2-3): 336-348. DOI: 10.1016/j.fishres.2007.12.020

Seijo JC, JF Caddy, J Euan. 1994. Spatial: Space-time dynamics in marine fisheries, a bioeconomic software package for sedentary species. *FAO Computerized Information Series: Fisheries* 6: 116p.

Seijo JC, E Pérez, JF Caddy. 2004. A simple approach for dealing with dynamics and uncertainty in fisheries with heterogeneous resource and effort distribution. *Marine and Freshwater Research* 55(3): 249-256. DOI: 10.1071/MF04040

Sumaila UR. 1998. Protected marine reserves as fisheries management tools: A bioeconomic analysis. *Fisheries Research* 37(1-3): 287-296. DOI: 10.1016/S0165-7836(98)00144-1

Vargas-López VG, F Vergara-Solana, F Arreguín-Sánchez. 2021. Effect of environmental variability on the individual growth of yellow abalone (*Haliotis corrugata*) and blue abalone (*Haliotis fulgens*) in the Mexican Pacific. *Regional Studies in Marine Science* 46: 101877. DOI: 10.1016/j.rsma.2021.101877

Received: 12 September 2022
Accepted: 3 November 2022