Universidad de Concepción

Dirección de Postgrado

Facultad de Ciencias Naturales y Oceanografía

Programa de Magíster en Ciencias con Mención en Pesquerías

Detección de indicios de agotamiento a través del uso de múltiples metodologías de datos limitados: El caso de la pesquería de Juan Fernández, Chile

Tesis presentada a la Facultad de Oceanografía de la Universidad de Concepción para optar al grado de Magíster en Ciencias con Mención en Pesquerías

ANGELO CRISÓSTOMO AGUILAR CHAGUA

Julio 2022

Concepción-Chile

Profesor Guía: Billy Ernst Elizalde

Profesor Guía:

Dr. Billy Ernst Elizalde
Departamento de Oceanografía
Universidad de Concepción

Comisión Evaluadora

Dr. Luis Cubillos Santander
Departamento de Oceanografía
Universidad de Concepción

Dr. Sergio Neira
Departamento de Oceanografía
Universidad de Concepción

Dra. Ana Parma
Centro Nacional Patagónico
CONICET

Director del Programa

Dr. Billy Ernst Elizalde
Departamento de Oceanografía
Universidad de Concepción

AGRADECIMIENTOS

Expreso mi más profundo y sincero agradecimiento a todas aquellas personas que con su ayuda han colaborado en la realización del presente trabajo. En especial a mi profesor guía Billy Ernst por su apoyo continuo en mi formación científica, personal y económica durante todo este proceso, especialmente por su paciencia y dedicar tiempo de calidad a nuestras horas de trabajo. Su importante guía fue crucial para finalizar satisfactoriamente este proceso.

A mis revisores de tesis Ana Parma y Luis Cubillos por darse el tiempo de contribuir con sus valiosos consejos, comentarios y revisiones continuas a la presente investigación.

A todos mis amigos, aquellos que estuvieron presentes durante toda o la mayor parte de la realización y desarrollo de esta tesis, gracias a aquellos que con respeto y decencia realizaron aportes a esta, por las divertidas conversaciones y viajes que ayudaron a reconfortarme durante todo este agotador proceso.

A la Universidad de Concepción por brindarme el apoyo económico para financiar mis estudios de maestría.

A todos ellos, muchas gracias.

TABLA DE CONTENIDO

ÍNDICE DE TABLAS

ÍNDICE DE FIGURAS

RESUMEN

La pesca puede impactar negativamente los recursos marinos, sus ecosistemas marinos, y la calidad de vida de las comunidades costeras que dependen de esta actividad. Por ello, la implementación de medidas de manejo requiere cuantificar correctamente el nivel de explotación. Los métodos tradicionales de evaluación de stock permiten cuantificar el nivel de explotación de los recursos pesqueros, pero estos tienen importantes requerimientos de datos que normalmente son imposibles de satisfacer en pesquerías con datos limitados. Esto ha motivado el desarrollo de diferentes métodos de evaluación orientados a pesquerías con pocos datos, cuya implementación se ha incrementado mucho durante los últimos años. Sin embargo, su uso generalizado tiene importantes limitaciones, especialmente la incapacidad para estimar biomasa o los puntos de referencia basados en el rendimiento máximo sostenible (RMS). No obstante, los métodos resultan ser útiles como herramientas para la detección temprana de indicios de sobre explotación. En la presente investigación se implementaron cuatro métodos de evaluación para pesquerías limitadas en datos, a partir de la consolidación de una base de datos biológica-pesquera de diferentes fuentes de información. Se emplearon métodos de capturas, tallas e índices de abundancia para evaluar indicios de sobreexplotación en las pesquerías de breca, anguila y jurel que se desarrollan en el Archipiélago de Juan Fernández. Los resultados mostraron indicios de sobre explotación en el stock de anguila, pero no en los

stocks de breca y jurel de Juan Fernández. Los valores de RMS estimados por los métodos de capturas pueden ser útiles como punto de partida para desarrollar recomendaciones de manejo, pero deben ser usados con precaución y en conjunto con un procedimiento sólido de manejo. Se espera que los resultados de esta investigación contribuyan en la elaboración de un plan de manejo para las principales pesquerías de peces en el Archipiélago Juan Fernández, Chile.

INTRODUCCIÓN

Contexto General

En el ámbito pesquero, con frecuencia los científicos y personas involucradas en la elaboración de políticas públicas deben enfrentarse al desafío que implica la toma de decisiones frente a situaciones inciertas. Las buenas prácticas en el manejo precautorio requieren tener la capacidad de usar la información disponible para la elaboración de medidas de conservación y/o administración (Declaración de Río sobre el Medio Ambiente y el Desarrollo, 1992). Sin embargo, en un contexto de pesquerías con datos limitados, la información disponible puede ser insuficiente en calidad y/o cantidad de datos (Dowling et al., 2019). Intentar implementar medidas de administración en tales condiciones resulta un desafío, ya que implica cuantificar el nivel de explotación de los recursos pesqueros. Las metodologías tradicionales de evaluación de stock permiten cuantificar el nivel de explotación por pesca, pero son altamente demandantes de información (Prince et al., 2015; Carruthers et al., 2014), haciéndolas poco prácticas su uso para un entorno de datos limitados. No obstante, un gran número de las pesquerías mundiales son consideradas como pesquerías de datos limitados y, a pesar de representar más del 80% de las capturas globales, carecen de evaluaciones formales (Costello et al., 2012).

Similarmente, en Chile solo una pequeña fracción de los stocks han sido formalmente evaluados. En el año 2020 se reportó 78 especies de peces marinos explotados por las flotas industriales y artesanales chilenas – incluyendo territorios insulares – (SERNAPESCA, 2020a), de las cuales solo 16, principalmente industriales, han sido evaluadas (SUBPESCA, 2021). Estas cifras ponen en evidencia las limitadas fuentes de información para la evaluación y gestión de los recursos explotados por la actividad pesquera, situación que suele ser recurrente, aunque no exclusiva, en la gran mayoría de pesquerías artesanales. En Chile, el sector artesanal ha ganado mayor importancia económica durante los últimos años con relación al sector industrial, llegando a contribuir hasta el 38% de los desembarques totales (SERNAPESCA, 2020b). Sin embargo, muchos de los recursos explotados por este sector - principalmente los peces litorales - no cuentan con medidas de administración pesquera (TNC, 2019). En consecuencia, los pescadores comerciales y recreativos, incentivados por el aporte económico que les proporciona la actividad, en el caso de los primeros, y por las limitadas regulaciones, han explotado los recursos marinos durante décadas llegando a evidenciarse claras señales de agotamiento (Godoy et al., 2010; 2013; 2016; TNC, 2019; Gaymer et al., 2013).

La pesca artesanal en Chile cumple un rol esencial en términos económicos y sociales. La extracción no responsable de los recursos marinos puede impactar significativamente en la economía local y las costumbres y/o creencias de las comunidades dedicadas tradicionalmente a esta actividad (e.g. Pesca en Isla de Pascua, Aburto et al., 2015). Por tanto, es importante implementar herramientas que permitan determinar oportunamente indicios de sobre explotación a fin de contribuir – en el corto plazo - a la gestión de las pesquerías con pocos datos; particularmente, en aquellas presentes en zonas insulares que, aunque puedan registrar capturas menores en comparación con otras, sus habitantes dependen exclusivamente de los recursos locales. Este es el caso de la comunidad pesquera del Archipiélago Juan Fernández.

Contexto específico

El archipiélago Juan Fernández se constituye de un conjunto de islas oceánicas (AJF) ubicadas aproximadamente a 360 millas náuticas frente a las costas de Valparaíso, Chile (Ernst et al., 2010). El conjunto de islas y una serie de montes submarinos y guyots conforman la dorsal de Juan Fernández, que dado su peculiaridad geológica y biogeográfica la hacen un sistema diferente al resto de la costa de Chile continental (Rozbaczylo y Castilla, 1987; Pequeño y Saéz, 2000). Históricamente, los recursos pesqueros aledaños a este sistema insular han sido extraídos por la comunidad Fernandeciana emplazada en la Bahía Cumberland (isla Robinson Crusoe). Esta actividad comprende la captura de crustáceos y peces, recursos que han sido el soporte económico y alimenticio de la comunidad durante más de un siglo.

El desarrollo económico de la comunidad Fernandeciana se sustenta en gran medida en torno a la actividad pesquera artesanal de crustáceos (Arana, 2012; Pladeco, 2009). Esta incluye principalmente a la langosta de Juan Fernández (*Jasus frontalis)* y al cangrejo dorado (*Chaceon chilensis*). Su alto valor económico y la falta de desarrollo en otros sectores han determinado que el esfuerzo pesquero se concentre principalmente en la explotación de ambos crustáceos. Sin embargo, esta actividad implica la captura previa de otros recursos, principalmente peces, los cuales son empleados como carnadas primarias o secundarias en el proceso de extracción de estos invertebrados (Arana, 2012). Así mismo, su afinidad alimentaria por los recursos ícticos anguila morena (*Gymnothorax porphyreus*) y breca (*Nemadactylus gayi*) ha inducido al desarrollo de una pesquería orientada a estas especies lo que a su vez ha promovido la captura de otras especies de fácil acceso y recolección como *Pseudocaranx chilensis* “jurel de Juan Fernández”, carnada esencial para el éxito de esta última. Por otro lado, la captura de peces, además de ser destinada a su uso como carnada, es empleada en la creación de artesanías y como fuente alimenticia de los isleños reportándose también importantes niveles de extracción (Ernst et al., 2010; Ernst et al., 2012).

De acuerdo con Ahumada y Queirolo (2014), el 94% de la carnada (en número) empleada en la pesquería de crustáceos (de un total de 19 especies) se encuentra representado por el jurel (45%), la breca (41%) y la anguila morena (8%), evidenciándose una dependencia de la pesquería asociada a la provisión de carnada de al menos estas tres especies de peces. Operacionalmente, el proceso habitual en la pesca de especies carnada se inicia dispersando cebo (pan) sobre el mar en conjunto con el aparejo de pesca "línea de mano no remolcada" (sin carnada) en superficie para la captura de ejemplares juveniles de jurel de Juan Fernández, los que a su vez son empleados en la captura de ejemplares adultos de la misma especie. La gran mayoría de la captura de esta especie (58%) se emplea como carnada en la captura de breca mediante el uso de espineles verticales u horizontales. Este último recurso es destinado en su mayoría a carnada en la pesca de crustáceos (65%), específicamente en la pesca de langosta. Como actividad complementaria, se emplean trampas para la captura de anguila morena, usada como carnada de langosta (95%) y de peces (5%) (Ahumada y Queirolo, 2014; Queirolo et al., 2011).

La historia de la pesquería de crustáceos en el Archipiélago Juan Fernández ha evidenciado cambios importantes en cuanto a infraestructura, técnicas y aparejos de pesca durante siglos (Eddy et al., 2010; Ernst et al., 2013a; Ernst et al., 2010; Manríquez, 2016; Ernst et al., 2018). Uno de los cambios más importantes fue la introducción de un huinche hidráulico a fines de los años 90, lo que generó un aumento significativo en el número de trampas langosteras que es posible revisar por día, principal factor que exigió – indirectamente - una mayor demanda de especies carnadas. Algunos estudios en relación con las especies carnadas dieron a conocer que:

- Para breca, los rendimientos asociados a la pesca de langosta durante la temporada 2014 – 2015 fueron menores a los de la temporada 2010 – 2011 (Ernst et al., 2016a). Asimismo, otros estudios afirman una reducción de las tallas (Ahumada y Queirolo, 2014), apreciación que ha sido mencionada anteriormente por los pescadores isleños (Arana et al., 2006).
- Para jurel de Juan Fernández, se cuenta con una pesquería orientada fuertemente a ejemplares juveniles por constituir la carnada primaria base de todas las pesquerías ícticas y de crustáceos (Ernst et al., 2013b).
- Para anguila morena, se ha reportado que durante la temporada 2017, fue considerada como la segunda especie carnada más utilizada en los subsistemas Alejandro Selkirk e Islas Desventuradas – solo después de breca – (Ernst et al., 2018). Además, los volúmenes extraídos en Alejandro Selkirk son similares e incluso superiores en algunos meses a Robinson Crusoe – Santa Clara teniendo en cuenta que en el primer

subsistema opera un menor número de embarcaciones (Ernst et al., 2016b).

Asimismo, *N. gayi* y *G. porphyreus* están catalogadas como especies locales y demersales (Mann, 1954; McCosker y Beárez, 2010; Tapia et al., 2017) por estar su hábitat restringido a la plataforma insular del archipiélago, la cual tiene una extensión geográfica bastante limitada. Además, el alto número de especies endémicas del archipiélago (como breca y jurel) lo hace un sistema altamente vulnerable a la sobre explotación frente a un eventual aumento del esfuerzo de pesca (Friedlander et al., 2016).

El interés de los isleños por el manejo sustentable de la pesquería de crustáceos ha permitido implementar en los últimos 15 años un programa de monitoreo permanente para la recopilación de información biológica/pesquera de estos recursos, y se ha manifestado en los esfuerzos por apoyar e implementar regulaciones pesqueras, algunas de las cuales fueron oficializadas por el gobierno de Chile desde el año 1935. Por el contrario, las especies ícticas, a pesar de desempeñar un rol fundamental en la pesquería de crustáceos e indirectamente en el bienestar de la comunidad de Juan Fernández, no han contado con un programa de monitoreo similar al primero (Ernst et al., 2013b), haciéndose evidente la limitada información disponible y la ausencia de medidas de regulación (Ahumada y Queirolo, 2014). Estos factores, en conjunto con la rentabilidad económica que genera la pesca de la langosta, han incentivado la explotación de las especies ícticas evidenciándose una menor disponibilidad y abundancia con algunos primeros indicios de agotamiento, lo que puede conllevar no solo a dificultades para el desarrollo de la pesquería de crustáceos, sino también a eventuales conflictos entre pescadores.

En ese contexto, es relevante hacer uso de la información disponible para desarrollar e implementar indicadores que permitan conocer el impacto que la pesca está generando sobre las principales especies carnadas (breca, anguila, y jurel de Juan Fernández) y que además orienten al desarrollo de un proceso adaptativo basado en ciencia para determinar e implementar, en el corto plazo, acciones de manejo.

En los últimos años se han desarrollado e implementado diferentes enfoques/metodologías para monitorear, evaluar y gestionar pesquerías con datos limitados disponiéndose en la actualidad de múltiples opciones (Dowling et al., 2015, 2016; McDonald et al., 2014, Carruthers et al., 2014). El uso de los métodos para datos limitados (DLM, por sus siglas en inglés) tiene valor en identificar las especies en riesgo, incluso si la evaluación no es suficientemente buena (Dowling et al., 2019), por lo que han sido empleados para establecer capturas biológicas aceptables (Newman et al., 2014, Cummings et al., 2016) o al menos para determinar límites o indicios de sobre explotación para poblaciones de peces con datos limitados (Dowling et al., 2015, Fitzgerald et al., 2018, Ramírez-Gonzáles et al., 2018). La presente tesis tiene como objetivo explorar y analizar, mediante métodos de datos limitados, si las especies carnadas breca (*Nemadactylus gayi*), anguila (*Gymnothorax porphyreus*) y jurel de Juan Fernández (*Pseudocaranx chilensis*), explotadas en el sistema de Juan Fernández, muestran evidencias de sobre explotación.

HIPÓTESIS

Debido a la alta vulnerabilidad que representa el ecosistema marino insular de Juan Fernández, la alta demanda de carnadas ícticas de breca (*Nemadactylus gayi)*, anguila morena (*Gymnothorax porphyreus*) y jurel de Juan Fernández (*Pseudocaranx chilensis*) por parte de las pesquerías de crustáceos, y el actual y potencial interés en la explotación de estos recursos con un fin alimentario directo, se plantea la siguiente hipótesis de trabajo:

Hipótesis de trabajo

La creciente presión de pesca ejercida por la flota artesanal sobre los recursos ícticos empleados como carnadas en la pesquería de crustáceos del Archipiélago Juan Fernández ha llevado – en todos los casos – a su sobre explotación.

OBJETIVOS

Objetivo general

- Determinar el nivel de explotación de los recursos ícticos de breca (*Nemadactylus gayi*), anguila morena (*Gymnothorax porphyreus*) y jurel de Juan Fernández (*Pseudocaranx. chilensis*) mediante metodologías limitadas en datos.

Objetivos específicos

- Implementar sistemas de indicadores múltiples de rendimiento para las pesquerías de breca, anguila morena y jurel de Juan Fernández en un contexto de datos limitados.
- Identificar los principales métodos de evaluación con datos limitados (DLM) para las pesquerías de breca, anguila y jurel de Juan Fernández en el archipiélago Juan Fernández.
- Aplicar métodos de datos limitados para evaluar indicios de agotamiento en los recursos breca, anguila y jurel de Juan Fernández en el archipiélago Juan Fernández.

CHAPTER 1

Detecting warning signs of depletion through multiple data limited methods in small-scale fisheries: The case of finfish Juan Fernández fisheries, Chile.

Angelo Aguilar[*,1]; Billy Ernst[1,2]; Luis Cubillos[1,3]

[1]Programa de Magíster en Ciencias con Mención en Pesquerías, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Concepción, Chile.

[2]Departamento de Oceanografía, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Chile.

[3]Centro COPAS COASTAL, Departamento de Oceanografía, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Casilla 160-C, Concepción, Chile.

ABSTRACT

Small-scale fisheries are an important source of food security, income, and cultural identity for millions of people in the world. Even when scientists, fishers and other stakeholders linked to the fisheries sector observe a decrease in the abundance and sizes of fishery resources, a lack of data can be a barrier to understanding the conservation status of marine resources. Determining the status of fish stocks typically involves data-intensive assessment methods, which cannot be implemented when data is limited. To address this data gap, new methods have been developed to overcome these difficulties. In this study, four data-limited assessment methods were implemented on three important bycatch stocks caught in the vicinity of Robinson Crusoe Island in Chile using a biological-fisheries database consolidated from various sources. Catch, sizes and abundance indices were used to assess depletion signs in for *Nemadactylus gayi (*morwong*), Gymnothorax porphyreus (*moray eel*)* and *Pseudocaranx chiliensis (trevally)* fisheries in Juan Fernández, Chile. The results did not show signs of depletion in terms of abundance and size for morwong and trevally but did for moray eel. Maximum sustained yield values estimated using catch methods could be useful as a starting point to develop management recommendations, but they must be used with caution and be accompanied by a robust management procedure. The results of this research can contribute to the development of a management plan for the main finfish fisheries in the Juan Fernández Archipelago in Chile.

KEYWORDS

Data-poor assessments; fisheries management; small-scale fisheries, Juan Fernández archipelago.

1 INTRODUCTION

Identifying robust management strategies for marine resources is one of the most difficult decisions faced by decision makers, frequently taken in a context of limited data. At a global level, many fisheries have limited data (Costello et al., 2012; Vasconcellos et al., 2005) – particularly small-scale fisheries (Smith et al., 2009) – which become evident in the quantity and/or quality of data (Dowling et al., 2019). Developing and executing management measures in such conditions is a constant challenge that involves the proactive assessment of fishing exploitation levels. Traditional stock assessment methods enable researchers to quantify fishing exploitation levels, but they are data demanding (Carruthers et al.,2014) and are almost impossible to use in a data-limited context, which is the reason why these fisheries lack formal assessments (Costello et al., 2012).

In Chile only a small fraction of fish stocks has been formally assessed and managed. In 2020, 78 species exploited by Chilean industrial and small-scale fleets were reported (SERNAPESCA, 2020a), of which only 16 have been formally assessed (SUBPESCA, 2021). Most resources that remain unassessed are those harvested by small-scale fleets. Although commercial and recreational fishers in this sector have observed declining catches and sizes of exploited species (Gaymer et al., 2013; Godoy et al., 2016, 2010; Godoy, 2013), a lack of data has continued to hinder the understanding of stock status and the implementation of efficient management measures. Data availability issues are most evident in remote areas that usually have high biodiversity, and/or in fisheries of low value such as the case of finfish fisheries in the Juan Fernández Archipelago.

The Juan Fernández Archipelago is located in the southeastern Pacific Ocean, off the coast of Valparaíso, Chile. Historically, the community that inhabits these islands have based their socioeconomic development in the exploitation of marine resources (Arana, 2012). Harvests of Juan Fernández lobster (*Jasus frontalis*), a species that is endemic to the system, has consolidated as the community's main activity (Ernst et al., 2016a; Pequeño and Sáez, 2000). The harvest of this resource requires large volumes of coastal finfish that are mainly used as bait (Ahumada and Queirolo,2014; Arana, 2012; Queirolo et al., 2011). Three species of coastal fish have been mainly used as bait for more than a century: *Nemadactylus gayi* (morwong), *Pseudocaranx chilensis* (JF trevally) and *Gymnothorax porphyreus* (moray eel). Unlike for lobster stocks, the exploitation and monitoring of these resources has produced limited biological-fisheries data because of their lower economic value. As a result, the fishing pressure, and the potential impact of non-sustainable exploitation that the lobster fishery may have on them is unknown, since it directly depends on the supply of at least three of these bait species. Despite various efforts by several institutions across the years, the implementation of regulation measures focused on these fish species has been hindered due to lack of specific scientific recommendations.

In recent years, several methods to monitor, assess and manage data limited fisheries have been developed and implemented (Carruthers et al., 2014; Dowling et al., 2016; Dowling et al., 2015; McDonald et al., 2014). Data limited methods (DLM) are useful tools to identify species at risk, even if the assessment is not scientifically sound (Dowling et al., 2019). Therefore, they have been used to establish biologically accepted catches (Cummings et al., 2016; Newman et al., 2014) or to determine over-exploitation limits or indices (Dowling et al., 2015; Fitzgerald et al., 2018; Ramirez-González et al., 2018) that can subsequently be used to implement conservation measures.

Even though finfish fisheries in the Juan Fernández Archipelago have existed for more than a century, showing persistence over time, the increased interest in harvesting morwong for direct human consumption and as lobster fishery bait, has led to considerable interest in determining the conservation status and trends of these stocks. The main objective of this study is to detect early depletion signs in terms of abundance and size using different stock assessment methods for data limited stocks and serve as an example for multi-model inference in a data-limited setting.

2 METHODS

2.1 The Study System

The Juan Fernández (JF) Archipelago is in the Southern Pacific Ocean (33° 37’S, 78°51’W) at 667 km off the port of San Antonio, Valparaíso – Chile. It is comprised of three islands organized in two sub-systems: Robinson Crusoe, Santa Clara (RC-SC) and Alejandro Selkirk (AS) (Arana, 2010; Ernst et al., 2010a) (Figure 1). The first two islands have an area of 47.9 and 2.2 km2, respectively, and are most proximate to the continent. The third, with an area of 49.5 km2 is located 167 km west of RC-SC. The JF system is characterized by: a) the presence of islands, islets and volcanic seamounts (Rodrigo and Lara,2014); b) having a large number of endemic species in land and marine environments (Friedlander et al., 2016; Pequeño and Sáez, 2000; Perez-Matus et al., 2014; Rodríguez-Ruiz et al., 2014; Vargas et al., 2011; Vargas-Gaete et al., 2014) and c) the presence of mesoscale and sub-mesoscale oceanographic structures that promote a high degree of connectivity within and among islands (Medel et al.,2018; Porobic et al., 2012). As a result of the biogeographical, geological and biodiversity conservation relevance of this system, the area was declared a National Park (1935), a World Biosphere Reserve by UNESCO (1977) and a Multiple Use Marine Protected Area by the Government of Chile (2016).

Historically, the residents of the archipelago have based their local economy on the extraction and trade of marine resources (Arana, 2012, 2010; Ernst et al., 2016a; Vargas-Gaete et al., 2014). The harvest of lobster *Jasus frontalis*, an endemic species of JF and Desventuradas Islands (ID), is the main source of income for the permanent residents of San Juan Bautista (~930 inhab.), in Robinson Crusoe, and temporary residents of Rada la Colonia (~54 inhab.), mainly comprised by residents from San Juan Bautista who travel to Alejandro

Selkirk during the lobster fishing season (October – May) (Arana, 2012; Ernst et al., 2010b). Historical information related to sustainable exploitation of lobster, a participative management on behalf of the community using control rules issued by the Government of Chile, and environmental friendly harvest procedures (Ernst et al., 2016a, 2013a, 2010b; Porobic et al., 2019) were key elements to obtain Marine Stewardship Council (MSC) Certification in 2015 (Arana and Scott, 2014). This recognition also served as an incentive to plan and develop research aimed at species associated to the lobster fishery, to maintain the MSC Certification (Ernst et al., 2016c, 2016a).

The lobster fishery and, to a lower extent, the golden crab fishery (*Chaceon chilensis*) demand the extraction of high volumes of fish resources mainly used as bait (Ahumada and Queirolo, 2014; Queirolo et al., 2011). Among these, JF trevally, a pelagic and endemic species from JF and ID, is the primary bait used in the extraction of other species. The standard fishing operation begins by scattering bread on the ocean surface as a lure for juvenile trevally which surround the vessel and are then harvested using hand lines. Subsequently, this specie is primarily used as bait in longlines and traps to catch morwong and moray eel, respectively. Both species are used mainly as secondary bait in lobster harvest operations (Ahumada and Queirolo, 2014; Queirolo et al., 2011); although they are sometimes aimed for direct human consumption and/or handcraft (Ernst et al., 2013b, 2010b).

Management measures related to the harvest of marine resources in JF mainly focus on lobster. These measures include formal (minimum legal size, season and no egg-carrying females, moratorium on entry of new participants) and informal regulations (exclusive fishing grounds called “marcas”) (Ernst et al., 2013a, 2010b). In the case of bait fisheries, morwong is allowed to be harvested with hand line and longline (200 hooks maximum). At present, the management committee at Juan Fernández, working jointly with local fishers and officers from the Under-Secretariat for Fisheries and Aquaculture (SUBPESCA), have been developing regulatory proposals for morwong, including increasing the size and reducing the number of hooks. Likewise, in accordance with local fisher’s self-regulations, the minimum harvest size imposed for morwong is 25 cm. Similar measures do not exist for the trevally and moray eel fisheries in JF.

2.2 Sources of information

The information came from fishery-dependent monitoring conducted by fishers throughout the years and samplers onboard primarily during the lobster season (October-May). The difficulties to continuously monitor the AS subsystem imposed by limited access is reflected in data availability. As a result, this research emphasized those data from the RC-SC sub-system, where the fishing effort is more intensive and continuous throughout the year.

2.2.1 Landing records

Landing records are based on the official declarations reported by small-scale fishers to the National Fisheries Service (SERNAPESCA). The term "landing" shall be used in this study as a synonym of catch considering that the records account for the total number of fish harvested during the fishing operation. A large majority of harvested fish are not landed at the port since they are used as bait in the crustacean fishery (lobster and crab). Variables associated with the effort units were recorded for each fishing trip (vessel name, date of sail and arrival), catches (harvested volume by species) and destination of the catches. The SERNAPESCA database contains records that cover the period 2001-2020, although the records for 2001 were excluded because they are incomplete. Annual catch was calculated by adding the declared catch by species in each fishing trip. Nevertheless, since it was impossible to identify the moray eel species, annual catches of this resource were included with the group of species classified as moray eel in the database (according to Dyer and Westneat (2010) 3 moray eel species have been reported in the RC-SC). It is worth mentioning that, in accordance with conversations with researchers in the area, the main moray eel specie harvested in RC-SC is *Gymnothorax porphyreus*. Similar problems were not detected in the case of morwong and trevally since they are easily identified by the fishers.

2.2.2 Monitoring Program

Continuous monitoring programs designed around the RC-SC sub-system started in 2006 (Ernst et al., 2010b). In 2009, they were extended to the AS (Ernst et al., 2010a); however, monitoring activities in those years mainly focused on the lobster fishery. In 2011, funded by SUBPESCA, monitoring programs were expanded to include species associated with the lobster fishery. At present, Universidad de Concepción is in charge of the continuity of the monitoring program, funded through projects under the Fishery and Aquaculture Research Fund (FIPA). These projects have gathered relevant information related to the marine resources exploited in the archipelago during the lobster fishing season (Ernst et al., 2019; Ernst et al., 2018, 2016b, 2015,2014, 2013b). Data related to the fleet (gear types, vessel), effort (trips, hauls, hooks), catch by species (number and weight) and biometric data (size and weight) were gathered during each fishing trip. In general, catch and size information covered periods 2011-2021 and 2015-2021, respectively. Following an analysis of the contribution of each gear type used in the catches of trevally, morwong and moray eel, it was decided to only use catches harvested using using hand line, vertical longline and traps, considering that they are the main gear types used in harvests of such resources.

2.2.3 Other sources of information

The data from the FIP 2009-31 project (Queirolo et al. 2011) were used to complement the existing monitoring program. The database contains size and catch information (in number) by trip and traps used for fish species of interest during period 2010-2011.

2.3 Data-limited assessment

The selection process for data-limited stock assessment methods was carried out using the online FishPath platform as a guide (https://www.fishpath.org/the-tool). This platform contains more than 40 published methods along with the data each method requires for its implementation as well as limitations and assumptions (Dowling et al., 2016). FishPath was designed to identify data-limited stock assessment methods that are most appropriate based on the available information and context of specific fisheries (Dowling et al., 2016). Considering the type and amount of data available, 4 methods were selected to explore the depletion signs in trevally, morwong and moray eel fisheries. The analyses were made using R Core Team (2021) and the implementation details are described below.

2.3.1 Catch-based methods

Maximum Sustained Yield based on Catch (catch-MSY) and its updated version (CMSY) (Froese et al., 2017) use time series of annual catches and prior knowledge of resilience to estimate the parameters of the Schaefer's surplus production model, namely, the intrinsic rate of population growth r and the carrying capacity of the environment K. CMSY is based on that r, the initial relative biomass

(B_0/K) and the final relative biomass (B_{end}/K) of the assessed species are known in qualitative terms (high, intermediate, or low) and that the value of K varies between (maximum catch)/r and 4*(maximum catch)/r or between 2*(maximum catch)/r and 12*(maximum catch)/r and depending on the level of biomass in the last year which it based on pre-defined rules detailed in Froese et al. (2017). The CMSY method can only be applied with the Schaefer's model, so that a symmetric production function is assumed, i.e., the biomass that produce the MSY is K/2 and MSY is rK/4. The method provides estimates of MSY, the fishing mortality that produces MSY (F_{MSY}), and the biomass that produces MSY (B_{MSY}), the relative size of the stock (B/B_{MSY}), and the fishing exploitation (F/F_{MSY}).

The Optimized Catch-Only Method (OCOM) is a method that requires a series of catches and natural mortality values to estimate "prior" distributions, one for the intrinsic population growth rate (r), based on natural mortality, and another for stock depletion (S), based on catch trend (Zhou et al. 2018). OCOM, similarly to CMSY, is governed by Schaefer's model so the parameters to be estimated are r and K. The estimation procedure utilizes a prior for r to solve K through the ratio B_{end}/K or stocks saturation (S). The estimation considered 10000 values for r and S, and the optimizations function ("optimize" in r) solved viable r-K pair to set upper and lower K values, which are not part of a prior range as the estimation of K in CMSY method (Zhou et al. 2018). An estimate of natural mortality was obtained using empirical equations based on life history invariants where $M =$

$4.899 * t_{max}^{-0.916}$ (Then et al., 2015), where t_{max} corresponds to maximum age. Both catch methods were implemented using the datalimited2 package, available on GitHub (Free 2018).

For morwong and trevally, life history parameters required to estimate M were obtained from Queirolo et al. (2011) (Table 1). For moray eel, due to the lack of information, the value of *M* was inferred from FishLife, a tool designed in R to predict the life history parameters of different fishes of the world based on taxonomic group information and available historical data (Thorson et al., 2017). For CMSY, the resilience values categorized as medium (0.2 < r < 0.8) for trevally and low (0.05 < r < 0.5) for morwong and moray eel were obtained from the FISHBASE database.

2.3.2 Length-based method

The method known as Length-Based Spawning Potential Ratio (LB-SPR) estimates the spawning potential ratio (SPR) based on life history parameters and size data (Hordyk et al., 2014b). Using maximum likelihood, LB-SPR finds relative values of F/M and size selectivity that minimize the difference between the observed and expected size composition of the catch. These values are used to estimate the SPR value as an index of status (Hordyk et al., 2014b, 2014a). LB-SPR requires certain life history parameters such as: asymptotic length (L_{∞}), ratio between natural mortality and the growth coefficient (M/k) and size of maturity (L_{50}).

The LB-SPR method was applied only to morwong because inference based on trevally or moray eel size frequency data was not considered appropriate for two reasons: First, the Juan Fernández trevally fishery targets mostly the juvenile fraction of the stock, operating mainly in coastal fishing grounds where trevally juveniles are found (Ahumada and Queirolo, 2014; Queirolo et al. 2011). Using LB-SPR on trevally data would violate the logistic selectivity assumption of this method. Second, biological sampling of moray eel catch is less frequent because of its ferocious behavior that complicates taking size measurements during normal fishing operations.

The size composition of morwong catch was obtained by regularly sampling the vertical longline operations. Size frequency of fork length (FL) were constructed after excluding extreme values due to observation errors (i.e., < 0.01 and > 0.99 percentiles). Biological and fisheries parameters were extracted from Queirolo et al. (2011) and, in the case of M, estimated based on the empirical equation mentioned above. The analysis was performed using the LBSPR package, available on CRAN.

2.3.3 Abundance indicators

CPUE is an indicator commonly used to represent the relative abundance of a stock. The potential effects of multiple variables on the CPUE need to be corrected by means of standardization techniques. To this end, data from variables that potentially affect CPUE are needed such as type of fleet, fishing gear, data on temporary, environmental, and oceanographic effects, or any variable that has an influence on resource availability. In this study, CPUE was defined as catch per fishing trip (for all 3 species) and catch per haul (morwong only).

Six Generalized Linear Mixed-Effects Models (GLMM) were considered in this study. Year and month were included as fixed effects, and vessel ID was included as a random effect. Mixed effect models were implemented using a logarithmic transformation of CPUE for the SERNAPESCA dataset (catch per trip for the 3 species) and GLMM with negative binomial distribution and natural logarithmic as link function for the monitoring dataset (catch per haul for morwong). We used a forward approach to compare different models, starting with the random effects, and including the month and year as fixed factors. Finally, the Akaike Information Criterion (AIC) (Akaike, 1974) was minimized to select the best model.

3 RESULTS

The suite of data-limited assessments performed for morwong, trevally, and moray eel generated three main sets of results with the following conclusions: a) The catch-based methods indicated that the stock status for morwong is critical and the stocks of trevally and moray eel are in recovery (OCOM) or critical (CMSY); b) CPUE trends for morwong and trevally are stable or slightly positive but they decline for moray eel; c) Size-method results for morwong are typical of a healthy population.

3.1 Catch-based method

Catch records of morwong, trevally and moray eel were used in the period from 2002 to 2020. The highest catches for the first two species were recorded in 2012 and in 2008, for the moray eel (Figures 2A and 3A). Values of r-K and biological reference points estimated using the CMSY method are shown in Table 2. Catches of coastal finfish exceeded the estimated MSY during the years 2004, 2008, 2009, 2011-2018 for morwong; 2008, 2009, 2011-2014, 2016, 2017 for trevally and 2003-2005, 2007-2009, 2011-2014 for moray eel (Figure 2A). In recent years, the stocks of the assessed species were estimated to reach levels below the limit reference point ($B < 0.5 * B_{MSY}$, Figure 2B) and are subject to overfishing ($F > F_{MSY}$, Figure 2C). On the other hand, the results of OCOM based on estimated values of M for morwong, trevally and moray eel are shown in Table 2. MSY values remained similar to those estimated using the CMSY method for morwong and trevally, but they differed for moray eel. Estimated biomass for trevally and moray eel stocks did not drop below the limit reference point ($B > 0.5 * B_{MSY}$) throughout the assessed period (Figure 3B). Nonetheless, in some years, fishing exploitation levels exceeded F_{MSY} (Figure 3C). In recent years, estimated biomass for morwong has been below the limit reference point ($B < 0.5 * B_{MSY}$) and subject to over-exploitation ($F > F_{MSY}$) (Figure 3B and 3C). The stock status trajectories based on changes of the relative biomass and fishing mortality estimated by CMSY and OCOM relative to the target biological reference points are shown in Figures 2D and 3D. Both catch-based methods indicate that the estimated stock biomass is below the target biological reference point ($B < B_{MSY}$). However, the over-exploitation level was uncertain since different results were obtained by the two catch methods for trevally and moray eel.

3.2 Length-based method

In periods 2010-2011 and 2015-2021, a total of 18,605 morwong individuals were measured. In general, sizes ranged from 21 cm - 72 cm FL, with a global mean length of 35.4 cm FL. Annual modal variation ranged from 30 - 35 cm FL. The year with the lowest sample size was 2015 (Table 3). Life history parameters used in LB-SPR are shown in Table 1. Length frequency distributions by year, with their corresponding fit of the LB-SPR model are shown in Figure 4. Specific parameter values F/M and SPR by year are shown in Table 3. The relative effort in terms of F/M estimated for every year are below the value that would lead to a strong decrease of SPR, relative yield and spawning stock biomass (F/M > 1, (Hordyk et al., 2014a) or F/M > 0.87, (Zhou et al., 2012), Figure 5a). With respect to SPR, estimated values on the basis of size frequencies by year were above the target reference point (SPR > 0.4), except during the last year (Figure 5b). In general, the results suggest that the morwong stock is in healthy condition (F/M < 1 and SPR > 40).

3.3 Abundance indices

The number of degrees of freedom, AIC, distribution family and source of information for the GLMM structures by species are shown in Table 4. The model with the lowest AIC was the one that included the year and month as fixed variables and boat as a random variable for Gaussian and Negative binomial distributions. The standardized CPUE for trevally and moray eel, considering fishing trip as the effort unit during the period 2002-2020 show positive and negative trends respectively. For morwong, the CPUE trend since 2010-2020 is relatively stable (Figure 6). On the other hand, standardized CPUE for morwong, based on the data from the monitoring program and using fishing haul as the unit of effort, demonstrates a similar trend in CPUE to that derived with data from SERNAPESCA, except in 2012, where a sudden increase is observed (Figure 7). Due to data limitations, it was not possible to build a CPUE indicator based on hauls or traps for trevally and moray eel, respectively.

4 DISCUSSION

This study is the first effort to assess the status of finfish resources used as bait in the Juan Fernández crustacean fishery, with the use of multiple data limited stock assessment methods. These resources are key for the lobster fishery which constitutes the basis of the economic livelihood of the inhabitants of Juan Fernández.

4.1 Catch-based method

The catch methods used in recent years categorize morwong, trevally and moray eel as over-fished stocks, and according to CMSY, subject to over-exploitation. The results of OCOM differ from those of CMSY in the case of trevally and moray eel. The discrepancies in the results may be caused by the different ways to estimate priori values for model parameters. Unlike CMSY, where the *r* parameter is estimated based on qualitative resilience levels; OCOM estimates are based on life history parameters, which are continuous variables. This leads to greater variability of F_{MSY} values (Zhou et al.,2018) which impacts the classification of the stock status in terms of F/F_{MSY}. In addition, the parameters estimated through these methods depend on a priori distributions in combination with the life history parameters. However, the OCOM model applied using a wide range of M values (0.1 – 0.7) consistently lead to stock status classified as over-fished in recent years (trevally and moray eel) and subject to over-exploitation (morwong) (supplementary material in Table S1 y Figure S1).

On the other hand, CMSY and OCOM assume stationary productivity parameters. The implication of this assumption is not to detect changes in productivity derived from a variable recruitment or an environmental regime shift, even though these phenomena are common in approximately 70% of fish stocks (Vert-Pre et al., 2013). In Australia, Wayte (2013) has reported a decrease in the recruitment of “jackass morwong” a species taxonomically related to morwong, due to a climate induced regime shift. Evaluating if similar changes have occurred is very difficult when the available data are limited. Research related to the characterization of environmental variability in period 2002-2017 in the Juan Fernández Archipelago and Desventuradas Islands do not show relevant changes. Nevertheless, a marked annual seasonality is noted, inverse to chlorophyll and sea surface temperature during the months of April and December (Andrade et al., 2012; Ernst et al., 2018). The relationship between these variables and resource productivity is still unknown and could compromise the reliability of estimated parameters. The limited capacity to detect changes in productivity or environmental regime changes is one of the main weaknesses of these methods, as a result of which they have been widely criticized for (Bouch et al., 2020; Free et al., 2020; Ovando et al., 2021b, 2021a; Sharma et al., 2021).

Catch methods generally assume that the catch decrease is directly related to over-exploitation. Nevertheless, the latter can be due to different factors such as changes in effort, under-reporting and/or environmental/ecological changes that are not related to fishing. A detailed analysis of catch and effort data recorded in fishing logbooks revealed that average catches per trip, with exception of moray eel, did not decrease as it would be expected if declines in catches were reflective of a decline in abundance (supplementary material in Figure S2). In addition, a closer examination of log-book declarations in terms of the lobster fishing season (1^{st} October – 14 May) revealed under-reporting of morwong, trevally and moray eel, which has become increasingly evident in recent years, mainly for moray eel (supplementary material in Figure S3). Considering that the fishing effort and average catches per trip has not significantly changed in the last decades, the decline in the historical catches of morwong and trevally – unlike moray eel - could be attributed more to under-reporting than to over-exploitation. On the other hand, the considerable fluctuations in the level of under-reporting may have compromised the estimation of K, MSY and B_{MSY}, and in turn the categorization of stock status in terms of B/B_{MSY}. A comparison of these values with those obtained when using as inputs the "*corrected catches*" based on the under-reporting rate during the lobster season indicates that the reference points based on biomass and MSY are underestimated (supplementary material in Table S2). Likewise, the categorization of trevally and moray eel stocks remains in a critical (CMSY) or in recovery (OCOM) state. However, the stock status of morwong changes significantly from a critical to a recovering (CMSY) or healthy (OCOM) population. These findings highlight the importance of quantifying the level of under-reporting and the effects it can have on the estimation of relative fishing mortality and relative stock status. Further, we should be aware that biases and inaccuracies in the estimation of these quantities may also occur when the stocks are lightly exploited (Free et al., 2020; Pons et al., 2020) or in recovery (Bouch et al., 2020). As the two methods led to different stock status classifications they were treated as complementary rather than competing approaches.

4.2 Length-based method

Estimation of SPR using LB-SPR indicates that the morwong stock appears to be in a healthy condition. Nevertheless, as in the case of catch methods, results of LB-SPR depend on the accuracy and precision of life history parameters used as input. In the available literature, three studies estimated the life history parameters for morwong (Díaz, 1982; Hernández, 2012; Queirolo et al., 2011). The range of L_∞ values reported in these studies was from 50 to 78 cm. LB-SPR is sensitive to underestimation of L_∞ (Hordyk et al., 2014b) because when larger sized individuals approach L_∞, the estimates of SPR increase quickly (Prince et al., 2015). Likewise, L_∞ depends on estimates on age (t_0) and remaining growth parameters (k) y which requires reliable age-length data. Such parameters were estimated by Queirolo et al. (2011) using otolith reading, one of the most reliable methods, from 33 individuals (size ranged from 22 to 47 cm FL). The maximum size recorded for morwong in our database is 72 cm FL. This may indicate a possible under-estimation of L_∞ and as a result, an over-estimation of the SPR values (supplementary material in Figure S4). On the other hand, LB-SPR assumes a non-differentiated growth between males and females. Studies performed by Hernández (2012) validate this assumption. With respect to estimated M and k values, they could vary significantly when they are estimated independently, but their ratio is less variable, whereby it is not a major problem in LB-SPR (Prince et al., 2014).

Size-related measures have long been used as indicators of response to stock depletion (Beverton and Holt, 1959; Cope and Punt, 2009; Froese, 2004). Size frequency distribution and their average for morwong revealed low variation during the study period (~ 33-36 cm FL). Likewise, annually, over 75% of recorded sizes were above size maturity (L_{50} = 29 cm FL, supplementary material Figure S5). When this occurs, yield and spawning biomass can be maintained at sustainable levels, even if high levels of fishing pressure are exercised (F/M > ~ 0.5 (Prince and Hordyk, 2018). These results also indicate that the fishing pressure would not have a significant impact on the decline of the stock, which directly coincides with F/M values estimated using LB-SPR.

4.3 Abundance indices

Standardization of catch and effort data to develop relative abundance indices of fish populations assumes that the explanatory variables available are sufficient to remove (or explain) most of the variation in the data that is not attributable to changes in abundance (Maunder and Punt 2004). Considering that catchability in Juan Fernández has not changed significantly over time, we considered that temporal variables (year, month) are enough to explain the variation in the data that is not attributable to changes in the abundance of stock. However, the CPUE also can be seriously affected by the inappropriate selection of the fishing effort unit. In this work, the fishing trip (for the 3 species) and fishing haul (morwong) were considered as the unit effort. However, the former measure of effort is too coarse, because the catch during a fishing trip can be influenced by various factors that directly affect yield (e.g.: number of hooks, effective fishing time, number of hauls, among others). When comparing the CPUE trend created with data from two sources and using different effort units (one smoother than the other) no changes were observed in the general trend of CPUE for morwong, with exception of the estimate for 2012 (Figure 7). Notably, this comparison was limited to the period 2010-2020. It is important to recall that the data collected by the monitoring program correspond to the records of samplers on board, which are more reliable than the SERNAPESCA dataset (collected by fishers), but they have lower coverage. The data used to standardize the CPUE of morwong had a coverage of less than 10% of the total trips. In 2012 there was a sudden rise in CPUE values (10 ind./haul), but that year the coverage was very low (0.58%), which is reflected in very wide confidence intervals. For trevally and moray eel, it was not possible to build a CPUE index based on fishing hauls due to an interruption of data records. It is important to gather continuous time series of data, to enable the use of more precise effort units to make comparisons and validate or refute the CPUE trends reported in this study. For example, in the case of moray eel, which is caught with traps, it would be essential to have data such as soaking time or number of traps set; for morwong, it would be important to record the number of hooks by longline or for trevally, the number of fishers, among others.

On the other hand, the relative abundance trend by itself tells us nothing about levels of abundance relative to MSY or abundance levels that may cause a risk of a fishery or a population collapse. However, it could be used as a signal of a healthy/recovery (positive trend) or critical/overfishing (negative trend) population.

According to the catch-based methods, the trevally and moray eel are in a critical or recovery state. The standardized CPUE trends were useful to validate the exploitation status estimated by the catch-based methods. The positive CPUE trend for trevally is a signal of population in recovery. This coincides with the stock status classification estimated by the OCOM method. On the other hand, the long-term negative CPUE trend of moray eel is a signal of a population in a critical state, which coincides with the CMSY results. Based on that, we categorized trevally and moray eel as stocks in recovery and critical states, respectively. Further, the morwong stock was originally classified as critical by the CMSY and OCOM method. However, when catches were corrected for underreporting, the classification of the morwong stock changed from critical to recovering. These results are consistent with the stable standardized CPUE trend, SPR values (> 40% per year), mean size, and a high percentage of mature specimens (>75% per year). Although size-based methods also involve a series of assumptions and potential risks of misclassification, if implemented correctly, they can provide valuable information, and often, better than methods that depend on catch alone (Ovando et al., 2021b). Unfortunately, length data for trevally and moray eel were not representative and prevented the use of length-based approaches. In addition, the scarce knowledge related to biological aspects such as size-at-maturity, did not allow the use of simple indicators such as those suggested by Froese (2004). These limitations shed light on the importance of focusing research on ecological, biological and fisheries aspects related to the species associated with lobster and collecting data that is required in order to implement and/or improve these and other data limited methods.

Our results emphasize the importance of quality, quantity, and efficient use of data, rather than the specific assessment models used to categorize stocks status. The simplicity and few requirements of data-limited methods make them attractive for many users, but the results obtained can be easily misinterpreted in the absence of good quality data and knowledge related to the historical context of a fishery (e.g., Eddy et al. (2010)). This study suggests that morwong, trevally and moray eel stocks are healthy, recovering and in a critical condition respectively.

TABLES

***Table 1**. Summary of biological and fisheries parameters for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel) obtained from Queirolo et al. 2011*

Parameters	**Morwong**	**Trevally**	**Moray eel**
Size of maturity (L_{50})	29	NA	NA
Maximum size (L_{max})	58	39	NA
Asymptotic length (L_{∞})	55.38	46.65	NA
Age at cero (t_0)	-1.72	-1.51	NA
Age of maturity (t_{mat})	4	NA	NA
Maximum age (t_{max})	14	9	NA
Growth coefficient (k)	0.13	0.15	NA
Size-weight relationship (a)	$1.8*10^{-5}$	10^{-7}	10^{-7}
Size-weight relationship (b)	2.97	3.73	3.73
Natural mortality – growth coefficient (M/k)	1.9	NA	NA

***Table 2**. Reference points estimated by CMSY and OCOM for Nemadactylus gayi, Pseudocaranx chilensis and Gymnothorax porphyreus.*

		CMSY						OCOM				
Stock	Resilience	K	r	F_{msy}	MSY	B_{msy}	M	K	r	F_{msy}	MSY	B_{msy}
Morwong	Low	524.49	0.34	0.17	44.98	262.25	0.25	460.07	0.37	0.19	43.03	230.04
Trevally	Medium	136.84	0.57	0.28	19.35	68.42	0.29	180.35	0.43	0.22	19.87	90.18
Moray eel	Low	412.07	0.28	0.14	28.64	206.04	0.20	279.88	0.31	0.15	21.93	139.94

***Table 3**. Mean annual size, sample size, and F/M and SPR estimates from LB-SPR for Nemadactylus gayi (morwong).*

Year	Mean Fork Length (cm)	Sample size	F/M	SPR
2010	35.4	1970	0.15 ± 0.06	0.80 ± 0.07
2011	33.9	1826	0.31 ± 0.07	0.62 ± 0.06
2015	34.9	650	0.10 ± 0.09	0.85 ± 0.13
2016	36.0	3390	0.21 ± 0.05	0.74 ± 0.05
2017	36.2	3121	0.01 ± 0.05	0.99 ± 0.08
2018	36.2	2373	0.04 ± 0.07	0.94 ± 0.1
2019	33.6	1517	0.45 ± 0.13	0.56 ± 0.07
2020	35.4	2176	0.18 ± 0.05	0.75 ± 0.06
2021	34.2	1582	0.90 ± 0.15	0.40 ± 0.04

Table 4. Results of CPUE standardization for *Morwong, Trevally and Moray eel using Sernapesca and Monitoring-program datasets. Akaike information criterion (AIC) values, model degrees of freedom (df), distribution family and data source*

		Morwong	Trevally	Moray eel		
Description	df	AIC	AIC	AIC	family	Source
Model1: logCpue ~ 1 + (1|vessel)	-	32565	36235	26286	Gaussian	SERNAPESCA
Model2: logCpue ~ year + (1|vessel)	18	32153	35696	25545	Gaussian	SERNAPESCA
Model3: logCpue ~ year + month + (1|vessel)	11	30999	34222	25017	Gaussian	SERNAPESCA
Model1: Cpue ~ 1 + (1|vessel)	-	26687	-	-	Negative Binom	MONITORING
Model2: Cpue ~ year + (1|vessel)	11	26592	-	-	Negative Binom	MONITORING
Model3: CPue ~ year + month + (1|vessel)	11	26533	-	-	Negative Binom	MONITORING

FIGURES

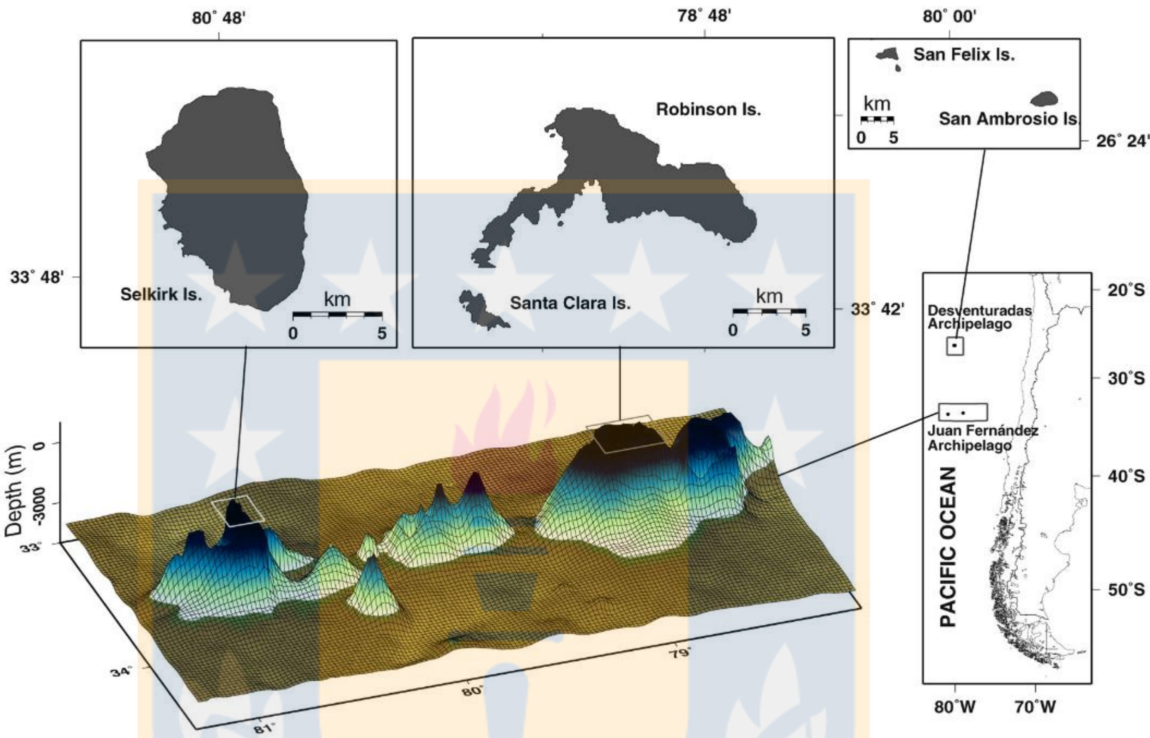

Figure 1. *The Juan Fernández Archipelago. Robinson Crusoe, Santa Clara and Selkirk Islands are peaks of a continuous submarine ridge extended in the east-west direction.*

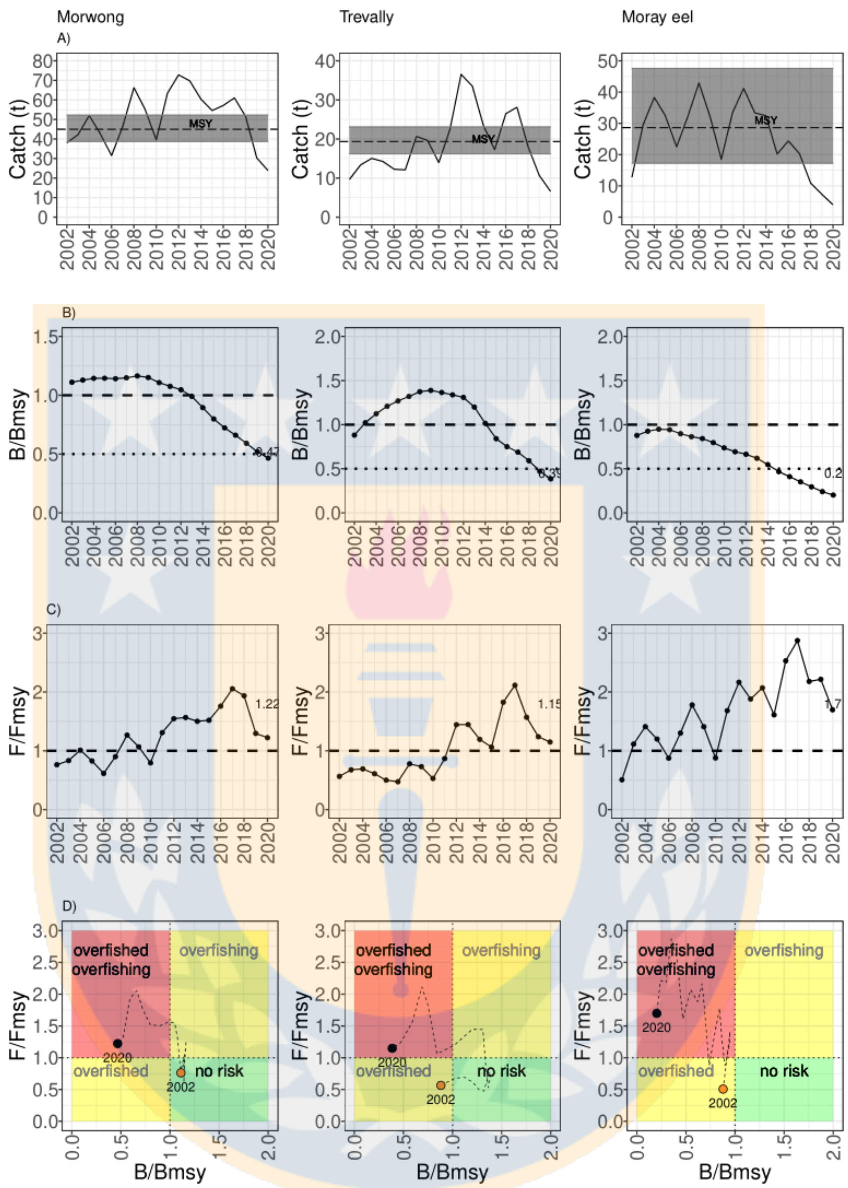

Figure 2. *CMSY results. (A) Catch histories and confidence Interval of MSY estimated by the model (shadowed area), (B) depletion of biomass with respect to* B_{MSY}*, (C)* F *ratio with respect to* F_{MSY} *and (D) phase diagram for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel) fisheries.*

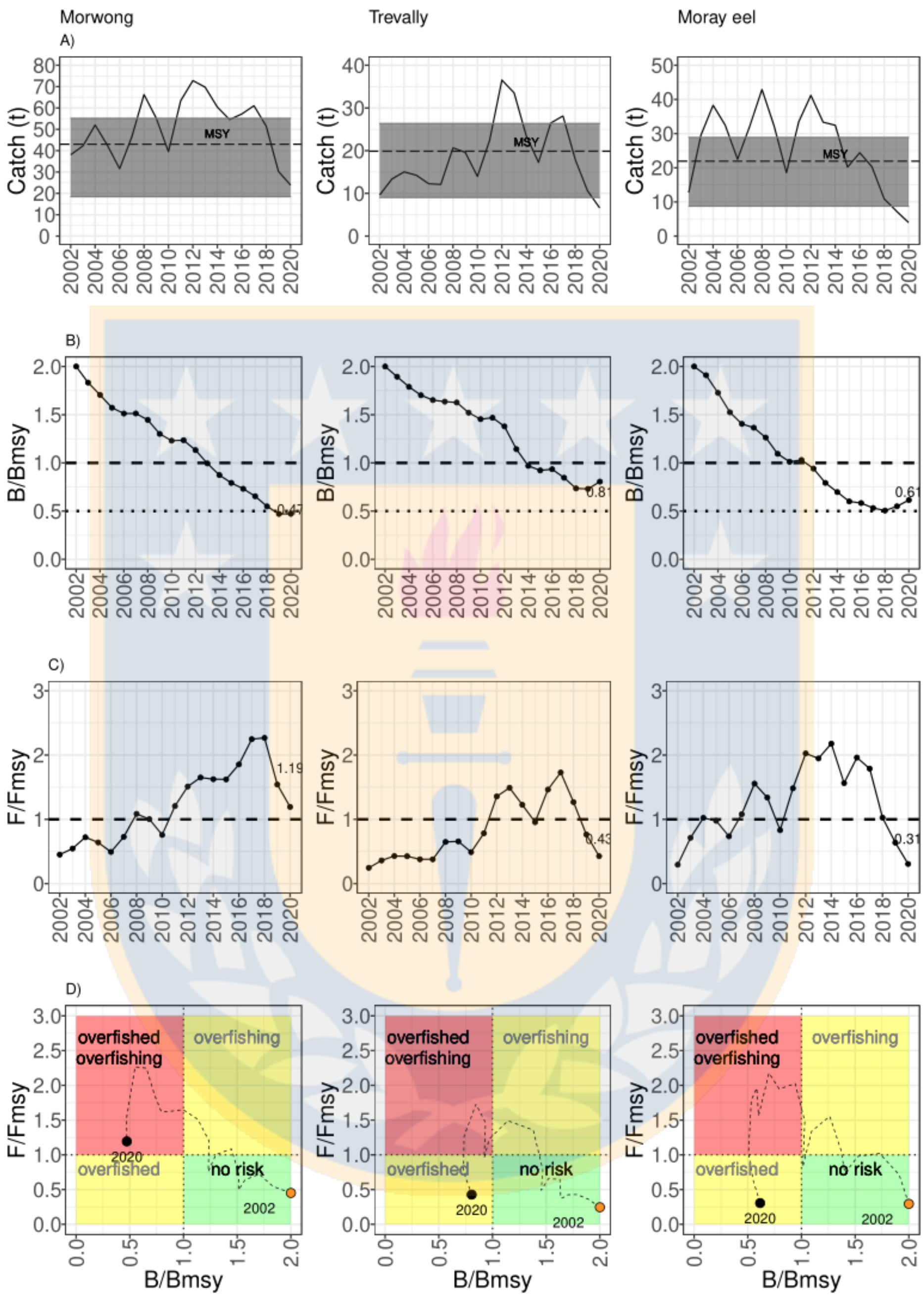

Figure 3. *OCOM results. (A) Catch histories and confidence Interval of MSY estimated by the model (shadowed area), (B) depletion of biomass with respect to B_{MSY}, (C) F ratio with respect to F_{MSY} and (D) phase diagram for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel) fisheries.*

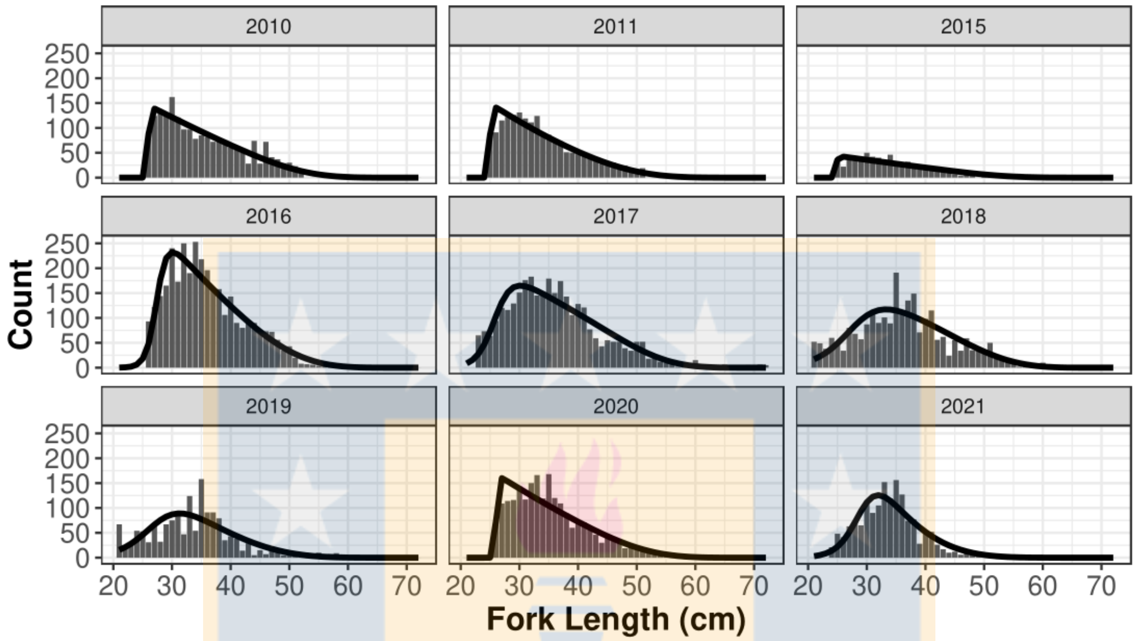

Figure 4. *Model fit to size frequency data for Nemadactylus gayi (morwong) in Robinson Crusoe based on parameters established in LBSPR (solid line).*

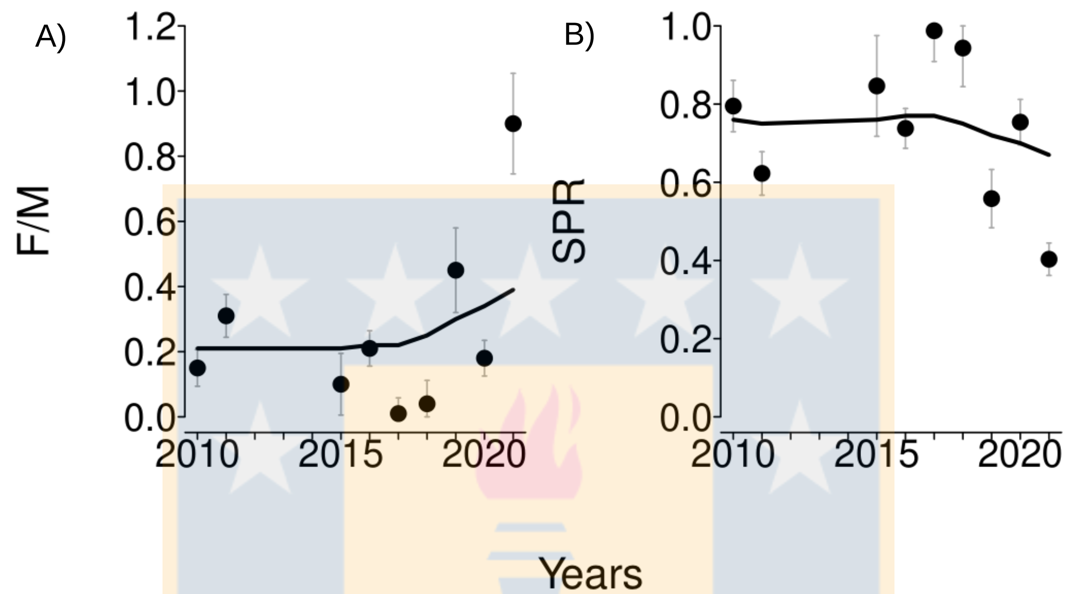

Figure 5. *Results obtained using LB-SPR method for Nemadactylus gayi. (A) Fishing and natural mortality ratio estimates and (B) spawning potential ratio in period 2010 - 2021. The black line corresponds to the smoother line of the estimated points.*

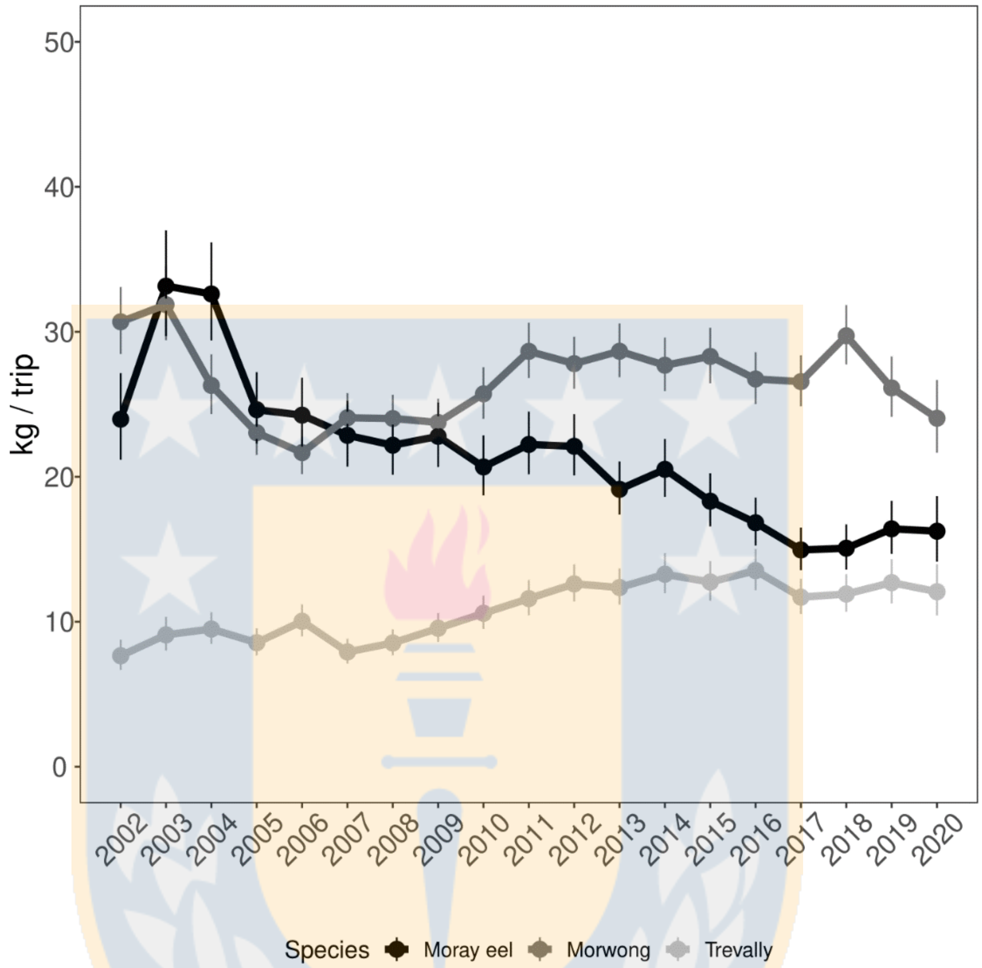

Figure 6. *Standardized CPUE with 95% confidence intervals for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel) in period 2002-2021, where CPUE is defined as catch in kg per trip. Source: SERNAPESCA.*

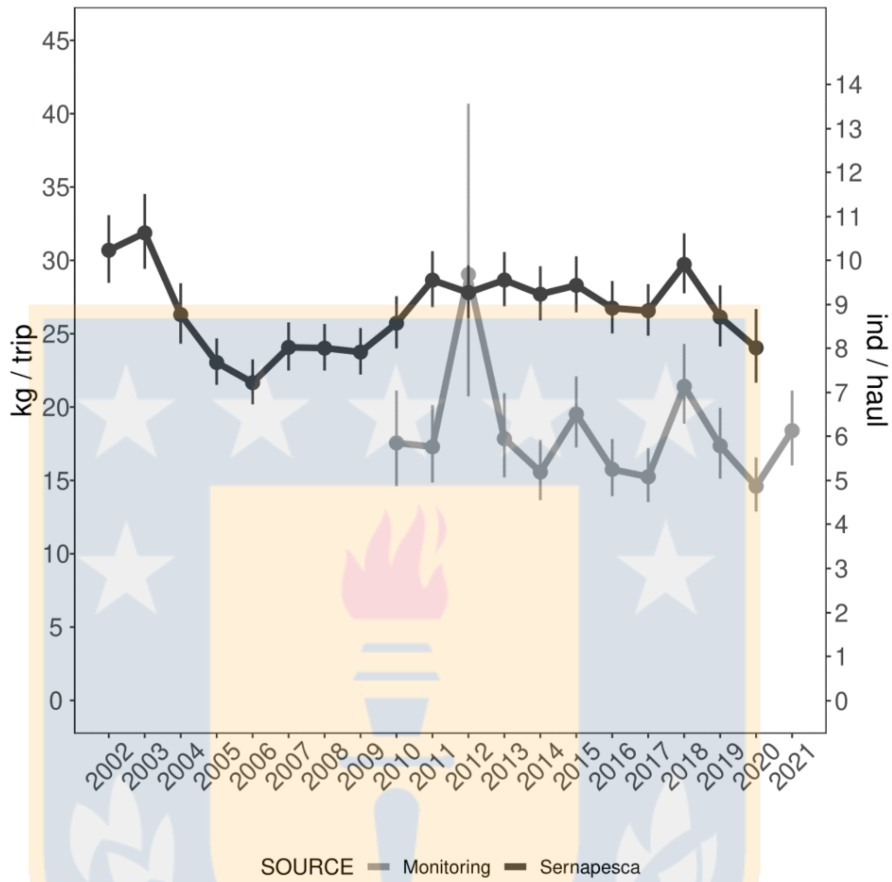

Figure 7. *Standardized CPUE with 95% confidence intervals for Nemadactylus gayi (morwong) in period 2010-2021, where CPUE is defined as catch in kg per trip (SERNAPESCA) and individuals per fishing haul (Monitoring program).*

ACKNOWLEDGMENTS

This research was supported by "Crustacean and associated fauna monitoring program in the Juan Fernández archipelago". We are grateful to Ana Parma, Dan Ovando and Sarah Calhoun for their suggestions and comments on this manuscript. We thank EDF (Layla Osman), SERNAPESCA (Rodrigo Riquelme), SUBPESCA (Guisela Muñoz, Aurora Guerrero) and Sindicato de trabajadores Independientes Pescadores Artesanales del Archipiélago Juan Fernández (STIPA) for sharing information and solve doubts when we need. Also, we acknowledge to onboard samplers for engaging the monitoring program and helping in collecting data.

REFERENCES

Ahumada, M., Queirolo, D., 2014. Explotación de peces asociada a la pesquería artesanal de langosta de Juan Fernández (Jasus frontalis). Latin american journal of aquatic research 42, 213–223.

Akaike, H. (1974). A new look at the statistical model identification. IEEE Transactions on Automatic Control AC, 19, 716-723.

Andrade, I., Hormazabal, S.E., Correa-Ramirez, M.A., 2012. Ciclo anual de la clorofila a satelital en el archipiélago de Juan Fernández (33°S), Chile. Latin american journal of aquatic research 40, 657–667.

Arana, P., 2010. La Isla de Robinson Crusoe. Ediciones Universitarias de Valparaíso, Chile., Ediciones Universitarias de Valparaíso, Chile. ed.

Arana, P., 2012. Recursos pesqueros del mar de Chile. Escuela de Ciencias del Mar, PUCV, Valparaíso, 308pp. Valparaíso - Chile.

Arana, P., Scott, I., 2014. The Chile Juan Fernández lobster (Jasus frontalis) trap fishery. Public Certification Report. Intertek Fisheries Certification.

Beverton, R.J.H., Holt, S.J., 1959. A Review of the Lifespans and Mortality Rates of Fish in Nature, and Their Relation to Growth and Other Physiological Characteristics, in: Ciba Foundation Symposium - The Lifespan of Animals (Colloquia on Ageing). John Wiley & Sons, Ltd, pp. 142–180 doi:10.1002/9780470715253.ch10

Bouch, P., Minto, C., Reid, D., 2020. Comparative performance of data-poor CMSY and data-moderate SPiCT stock assessment methods when applied to data-rich, real-world stocks. ICES Journal of Marine Science 78. doi:10.1093/icesjms/fsaa220

Carruthers, T.R., Punt, A.E., Walters, C.J., MacCall, A., McAllister, M.K. Dick, E.J., Cope, J., 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153, 48–68. doi:10.1016/j.fishres.2013.12.014

Charnov, E., Gislason, H., Pope, J., 2013. Evolutionary assembly rules for fish life histories. Fish and Fisheries 14, 213–224. doi:10.1111/j.1467-2979.2012.00467.x

Cope, J., Punt, A., 2009. Length-Based Reference Points for Data-Limited Situations: Applications and Restrictions. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1, 169–186. doi:10.1577/C08-025.1

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O., Lester, S.E., 2012. Status and Solutions for the World's Unassessed Fisheries. Science 338, 517–520. doi:10.1126/science.1223389

Cummings, N., Sagarese, S., Huynh, Q.C., 2016. An alternative approach to setting annual catch limits for data-limited fisheries: Use of the DLMtool and mean length estimator for six US Caribbean stocks. SEDAR46-RW-03. North Charleston, SC.

Díaz, M., 1982. Estimación lepidométrica de la edad y del crecimiento de la Breca (Acantholatris gayi) del archipiélago de Juan Fernández (PhD thesis). Tesis para optar al Título de Ingeniero Pesquero. Escuela de Ciencias del Mar. Pontificia Universidad Católica de Valparaíso, 124 pp., Valparaíso-Chile.

Dowling, N.A., Dichmont, C.M., Haddon, M., Smith, D.C., Smith, A.D.M., Sainsbury, K., 2015. Empirical harvest strategies for data-poor fisheries: A review of the literature. Fisheries Research, Development, testing, and evaluation of data-poor assessment and fisheries management methods 171, 141–153. doi:10.1016/j.fishres.2014.11.005

Dowling, N.A., Smith, A.D.M., Smith, D.C., Parma, A.M., Dichmont, C.M., Sainsbury, K., Wilson, J.R., Dougherty, D.T., Cope, J.M., 2019. Generic solutions for data-limited fishery assessments are not so simple. Fish and Fisheries 20, 174–188. doi:10.1111/faf.12329

Dowling, N., Wilson, J., Rudd, M., Babcock, E., Caillaux, M., Cope, J., Dougherty, D., Fujita, R., Gedamke, T., Gleason, M., Hordyk, A., Maina, G., Mous, P., Ovando, D., Parma, A., Prince, J., Revenga, C., Rude, J., Victor, S., 2016.

FishPath: A Decision Support System for Assessing and Managing Data- and Capacity- Limited Fisheries. doi:10.4027/amdlfs.2016.03

Dyer, B., Westneat, M., 2010. Taxonomy and biogeography of the coastal fishes of Juan Fernández Archipelago and Desventuradas Islands, Chile. Rev. Biol. Mar. Oceanogr. 45, 589–617.

Eddy, T., Gardner, J., Perez-Matus, A., 2010. Applying Fishers' Ecological Knowledge to Construct Past and Future Lobster Stocks in the Juan Fernández Archipelago, Chile. PloS one 5, e13670. doi:10.1371/journal.pone.0013670

Ernst, B., Chamorro, J., Manríquez, P., Orensanz, L., Parma, A., Porobic, J., Román, C., 2013a. Sustainability of the Juan Fernández lobster fishery (Chile) and the perils of generic science-based prescriptions. Global Environmental Change 23, 1381–1392. doi:10.1016/j.gloenvcha.2013.08.002

Ernst, B., Oyarzun, C., Vilches, J., Rivara, P., Tapia, B., Alvarez, C., Molina, E., Leiva, F., Gauthier, S., 2016a. Estudio Ecosistémico de las pesquerías del 600 sitio piloto Archipiélago de Juan Fernández. Fase Metodológica. Universidad de Concepción, Concepción.

Ernst, B., Parada, C., Chamorro, J., Manríquez, P., Pino, J., Tapia, B., Sandoval, M., 2018. Programa de seguimiento de las principales pesquerías nacionales, año 2017. Pesquerías de Crustáceos del archipiélago Juan Fernández. Univerisad de Concepción, Concepción.

Ernst, B., Parada, C., Chamorro, J., Manríquez, P., Porobic, J., Román, C., Rivara, P., Pino, J., Reyes, A., 2014. Programa de monitoreo de las principales pesquerías de Juan Fernández. Proyecto FIP N° 2013-15. Univerisad de Concepción, Concepción.

Ernst, B., Parada, C., Manríquez, P., Chamorro, J., Retamal, P., Román, C., Porobic, J., Frusher, S., Parma, A., Orensanz, J., 2010a. Dinámica poblacional y pesquera de la langosta en la isla Alejandro Selkirk. Proyecto FIP N 2008-24. Univerisad de Concepción, Concepción.

Ernst, B., Parada, C., Manríquez, P., Orensanz, J., Chamorro, J., 2010b. Strengthening of traditional territorial tenure system through protagonism in monitoring activities by lobster fishermen from the Juan Fernández Islands, Chile. Bulletin of Marine Science -Miami- 86, 315–338.

Ernst, B., Pino, J., Chamorro, J., Manríquez, P., Rivara, P., 2016b. Programa de Seguimiento de las Principales Pesquerías Nacionales, año 2015. Pesquerías de Crustáceos del archipiélago Juan Fernández. Univerisad de Concepción, Concepción.

Ernst, B., Pino, J., Chamorro, J., Manríquez, P., Rivara, P., Porobic, J., 2015. Programa de Seguimiento de las Principales Pesquerías Nacionales, año

2014. Pesquerías de Crustáceos del archipiélago Juan Fernández. Univerisad de Concepción, Concepción.

Ernst, B., Pino, J., Chamorro, J., Manríquez, P., Rivara, P., Tapia, B., Parada, C., Sandoval, M., Cornejo, S., 2019. Boletín de difusión. Programa de seguimiento de las principales pesquerías nacionales, año 2018. Pesquerías de crustáceos del archipiélago Juan Fernández. Instituto de Fomento Pesquero.

Ernst, B., Rivara, P., Tapia, B., Santa-Cruz, F., Espinoza, L., Manríquez, P., Molina, E., 2016c. Evaluación directa de la breca (Nemadactylus gayi, Kner 1865) en torno a las islas Robinson Crusoe y Santa Clara. Proyecto: GEF- UNDP Hacia un Manejo Ecosistémico del Gran Ecosistema Marino de la Corriente de Humboldt (GEMCH) – PIMS 4147. Univerisad de Concepción, Concepción.

Ernst, B., Salas, Estrella, Porobic, Javier, Román, C., Chamorro, Julio, Manríquez, Pablo, Pérez, Marco, Schiller, Rut, Recabarren, Sheila, Contreras, Alessandra, Melgarejo, Marcial, Chamorro, Manuel, Schiller, Henrry, Schiller, Oscar, Lemus, Rodrigo, Mieres, Marcelo, 2013b. Monitoreo de las principales pesquerías del archipiélago Juan Fernández, año 2012. Subsecretaría de Pesca - Proyecto N° 4728-36-LP12. Universidad de Concepción, Concepción.

Fitzgerald, S.P., Wilson, J.R., Lenihan, H.S., 2018. Detecting a need for improved management in a data-limited crab fishery. Fisheries Research 208, 133–144. doi:10.1016/j.fishres.2018.07.012

Free CM (2018) datalimited2: More stock assessment methods for data-limited fisheries. R package version 0.1.0. https://github.com/cfree14/datalimited2

Free, C.M., Jensen, O.P., Anderson, S.C., Gutierrez, N.L., Kleisner, K.M., Longo, C., Minto, C., Osio, G.C., Walsh, J.C., 2020. Blood from a stone: Performance of catch-only methods in estimating stock biomass status. Fisheries Research 223, 105452. doi:10.1016/j.fishres.2019.105452

Friedlander, A., Ballesteros, E., Caselle, J., Gaymer, C., Palma, A., Petit, I., Varas, E., Wilson, A., Sala, E., 2016. Marine Biodiversity in Juan Fernández and Desventuradas Islands, Chile: Global Endemism Hotspots. PLOS ONE 11. doi:10.1371/journal.pone.0145059

Froese, R., 2004. Keep it simple: Three indicators to deal with overfishing. Fish and Fisheries 5, 86–91. doi:10.1111/j.1467-2979.2004.00144.x

Froese, R., Demirel, N., Coro, G., Kleisner, K., Winker, H., 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries 18, 506–526. doi:10.1111/faf.12190

Gaymer, C., Aburto, J., Acuña, E., Bodini, A., Carcamo, F., 2013. Base de conocimiento y construcción de capacidades para el uso sustentable de los ecosistemas y recursos marinos de la ecorregión de Isla de Pascua. Licitación 4728- 33-Le12. Subsecretaría Pesca, p.191. Subsecretaría de Pesca y Acuicultura.

Godoy, N., 2013. Pesquería artesanal por buceo de peces de roca en el centro norte de Chile: diagnóstico del sistema social-ecológico y los desafíos para su sustentabilidad. (PhD thesis). Pontificia Universidad Católica de Chile, Santiago, Chile.

Godoy, N., Gelcich, S., Castilla, J., Lima, M., Smith, A., 2016. Artisanal Spearfishery in Temperate Nearshore Ecosystems of Chile: Exploring the Catch Composition, Revenue, and Management Needs. Marine and Coastal Fisheries 8, 436–447. doi:10.1080/19425120.2016.1185062

Godoy, N., Gelcich, S., Vásquez, J., Castilla, J., 2010. Spearfishing to depletion: Evidence from temperate reef fishes in Chile. Ecological applications: a publication of the Ecological Society of America 20, 1504–11. doi:10.1890/09-806

Hernández, A., 2012. Edad, crecimiento y biología reproductiva de la breca Nemadactylus gayi (Kner, 1865) en la isla de Robinson Crusoe (PhD thesis). Pontificia Universidad Católica de Valparaíso, Valparaíso - Chile.

Hordyk, A., Ono, K., Sainsbury, K., Loneragan, N., Prince, J., 2014a. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES Journal of Marine Science. doi:10.1093/icesjms/fst235

Hordyk, A., Ono, K., Valencia, S., Loneragan, N., Prince, J., 2014b. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES Journal of Marine Science. doi:10.1093/icesjms/fsu004

Jensen, A.L., 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53, 820–822. doi:10.1139/f95-233

Martell, S., Froese, R., 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries 14, 504–514.

Maunder, M. N., & Punt, A. E. (2004). Standardizing catch and effort data: a review of recent approaches. Fisheries research, 70(2-3), 141-159.

McDonald, G., Carcamo, R., Fujita, R., Gedamke, T., Karr, K., Wilson, J., 2014. A Multi-indicator Framework for Adaptive Management of Data-limited Fisheries with a Case Study from Belize., in: Proceedings of the 67th Gulf and Caribbean Fisheries Institute November 3 - 7, 2014 Christ Church, Barbados. pp. 107–114.

Medel, C., Parada, C., Morales, C.E., Pizarro, O., Ernst, B., Conejero, C., 2018. How biophysical interactions associated with sub- and mesoscale structures and migration behavior affect planktonic larvae of the spiny lobster in the Juan Fernández Ridge: A modeling approach. Progress in Oceanography 162, 98–119. doi:10.1016/j.pocean.2018.02.017

Newman, D., Carruthers, T., MacCall, A., Porch, C., Suatoni, L., 2014. Improving the science and management of data-limited fisheries: An evaluation of current methods and recommended approaches. Natural Resources Defense Council, NRDC report R 14–09.

Ovando, D., Free, C.M., Jensen, O.P., Hilborn, R., 2021a. A history and evaluation of catch-only stock assessment models. Fish and Fisheries n/a. doi:10.1111/faf.12637

Ovando, D., Hilborn, R., Monnahan, C., Rudd, M., Sharma, R., Thorson, J.T., Rousseau, Y., Ye, Y., 2021b. Improving estimates of the state of global fisheries depends on better data. Fish and Fisheries 22, 1377–1391. doi:10.1111/faf.12593

Pequeño, G., Sáez, S., 2000. Los peces litorales del archipiélago de Juan Fernández (Chile): Endemismo y relaciones ictiogeográficas. Investigaciones marinas 28, 27–37. doi:10.4067/S0717-71782000002800004

Perez-Matus, A., Ramirez, F., Eddy, T., Cole, R., 2014. Subtidal reef fish and macrobenthic community structure at the temperate Juan Fernández

Archipelago, Chile. Latin American Journal of Aquatic Research 42, 814–826. doi:10.3856/vol42-issue4-fulltext-9

Pons, M., Cope, J., Kell, L., 2020. Comparing performance of catch-based and length-based stock assessment methods in data-limited fisheries. Canadian Journal of Fisheries and Aquatic Sciences 77. doi:10.1139/cjfas-2019-0276

Porobic, J., Fulton, E.A., Parada, C., Frusher, S., Ernst, B., Manríquez, P., 2019. The impact of fishing on a highly vulnerable ecosystem, the case of Juan Fernández Ridge ecosystem. PLOS ONE 14, e0212485. doi:10.1371/journal.pone.0212485

Porobic, J., Parada, C., Ernst, B., Hormazábal, S.E., Combes, V., 2012. Modeling the connectivity of Juan Fernández rock lobster (Jasus frontalis), subpopulations through a biophysical model. Latin American Journal of Aquatic Research 40, 613–632. doi:10.3856/vol40-issue3-fulltext-11

Prince, J., Hordyk, A., 2018. What to do when you have almost nothing: A simple quantitative prescription for managing extremely data-poor fisheries. Fish and Fisheries 20. doi:10.1111/faf.12335

Prince, J., Hordyk, A., Valencia, S., Loneragan, N., Sainsbury, K. (2014). Revisiting the concept of Beverton-Holt Life History Invariants with the aim of informing data-poor fisheries assessment. ICES Journal of Marine

Science. 10.1093/icesjms/fsu011.

Prince, J., Victor, S., Kloulchad, V., Hordyk, A., 2015. Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. Fisheries Research, Development, testing, and evaluation of data-poor assessment and fisheries management methods 171, 42-58. doi:10.1016/j.fishres.2015.06.008

Queirolo, D., Ahumada, M., Plaza, G., Saavedra, J., Arana, P., Escobar, R., Merino, J., Gaete, E., Vivanco, M., Ruby, R., 2011. Alternativas de carnada en la pesquería de langosta de Juan Fernández (Jasus frontalis), para disminuir el impacto sobre especies ícticas del archipiélago (FIP 2009-31). Pontificia Universidad Católica de Valparaíso, Valparaíso - Chile.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ramirez-González, J., Banda-Cruz, G., Moreno, J., Ovando, D., Reyes, H., Rosero, P., Timpe, I., 2018. Implementation of a multiple indicator system for fisheries with limited information in a context of co-management, case study: Spiny lobster fishery in the Galapagos Marine Reserve. Ocean & Coastal Management 154, 20-25. doi:10.1016/j.ocecoaman.2017.12.027

Rodrigo, C., Lara, L.E., 2014. Plate tectonics and the origin of the Juan Fernández

Ridge: Analysis of bathymetry and magnetic patterns. Latin american journal of aquatic research 42, 907–917. doi:10.3856/vol42-issue4-fulltext-15.

Rodríguez-Ruiz, M.C., Andreu-Cazenave, M., Ruz, C.S., Ruano Chamorro, C., Ramírez, F., González, C., Carrasco, S.A., Pérez-Matus, A., Fernández, M., 2014. Initial assessment of coastal benthic communities in the Marine Parks at Robinson Crusoe Island. Latin American Journal of Aquatic Research 42, 918–936. doi:10.3856/vol42-issue4-fulltext-16.

SERNAPESCA, 2020a. Anuario Estadístico de Pesca y Acuicultura 2020. Desembarques y Acuicultura. Desembarque industrial y artesanal por especie y mes. URL: http://www.sernapesca.cl/informacion-utilidad/anuarios estadisticos-de-pesca-y-acuicultura (Accedido 22 de octubre 2021). Servicio Nacional de Pesca y Acuicultura.

Sharma, R., Winker, H., Levontin, P., Kell, L., Ovando, D., Palomares, M.L.D., Pinto, C., Ye, Y., 2021. Assessing the Potential of Catch-Only Models to Inform on the State of Global Fisheries and the UN's SDGs. Sustainability 13, 6101. doi:10.3390/su13116101

Smith, D., Punt, A., Dowling, N., Smith, A., Tuck, G., Knuckey, I., 2009. Reconciling approaches to the assessment and management of data-poor species and fisheries with Australia's harvest strategy policy. Marine and

Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1, 244–254.

SUBPESCA, 2021. Estado de situación de las principales pesquerías chilenas, año 2020. URL: https://www.subpesca.cl/portal/618/articles-110503_recurso_1.pdf. Subsecretaría de Pesca y Acuicultura.

Then, A.Y., Hoenig, J.M., Hall, N.G., Hewitt, D.A., Handling editor: Ernesto Jardim, 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science 72, 82–92. doi:10.1093/icesjms/fsu136

Thorson, J.T., Munch, S.B., Cope, J.M., Gao, J., 2017. Predicting life history parameters for all fishes worldwide. Ecological Applications 27, 2262–2276. doi:10.1002/eap.1606

Vargas, R., Reif, A., Faúndez, M.J., 2011. The forests of Robinson Crusoe Island, Chile: An endemism hotspot in danger. Bosque (Valdivia) 32, 155–164. doi:10.4067/S0717-92002011000200006

Vargas-Gaete, R., Smith-Ramirez, C., Gonzalez, C., Fernandez, M., 2014. Reserva de la Biósfera Archipiélago Juan Fernández: Endemismo para conservar. pp. 126–143.

Vasconcellos, M., Cochrane, K., Kruse, G.H., Gallucci, V.F., Hay, D.E., Perry, R.I., Peterman, R.M., Shirley, T.C., Spencer, P.D., Wilson, B., 2005. Overview of world status of data-limited fisheries: Inferences from landings statistics.

Vert-Pre, K., Amoroso, R., Jensen, O., Hilborn, R., 2013. Frequency and Intensity of Productivity Regime Shifts in Marine Fish Stocks. Proceedings of the National Academy of Sciences of the United States of America 110. doi:10.1073/pnas.1214879110

Wayte, S., 2013. Management implications of including a climate-induced recruitment shift in the stock assessment for jackass morwong (Nemadactylus macropterus) in south-eastern Australia. Fisheries Research 142, 47–55. doi:10.1016/j.fishres.2012.07.009

Zhou, S., Punt, A.E., Smith, A.D.M., Ye, Y., Haddon, M., Dichmont, C.M., Smith, D.C., 2018. An optimized catch-only assessment method for data poor fisheries. ICES Journal of Marine Science 75, 964–976. doi:10.1093/icesjms/fsx226

Zhou, S., Yin, S., Thorson, J., Smith, A.D.M., Fuller, M., 2012. Linking fishing mortality reference points to life history traits: An empirical study. Canadian Journal of Fisheries and Aquatic Sciences 69, 1292–1301. doi:10.1139/f2012- 060

SUPPLEMENTARY MATERIAL

Table S1. *Natural mortality estimated values for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel) using various bioanalogical approaches.*

Authors	**Equations**	**Morwong**	**Trevally**	**Moray eel**
Then et al. (2015)	$4.899 * t_{max}^{-0.916}$	0.25	0.290	NA
Then et al. (2015)	$4.118 * k^{0.73} * L_{\infty}^{-0.33}$	0.44	0.655	NA
Charnov et al. (2013)	$1.82 * k$	0.24	0.273	NA
Jensen (1996)	$1.65/t_{mat}$	0.41	NA	NA
Thorson et al. (2017)	FishLife	NA	NA	0.2

Table S2. *Reference points estimated by CMSY and OCOM using corrected catch as input for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel).*

		CMSY						OCOM				
Stock	Resilience	K	r	F_{msy}	MSY	B_{msy}	M	K	r	F_{msy}	MSY	B_{msy}
Morwong	Low	595.01	0.36	0.18	54.18	297.50	0.25	608.60	0.41	0.20	58.13	304.30
Trevally	Medium	179.33	0.57	0.28	25.35	89.66	0.29	196.42	0.44	0.22	21.92	98.21
Moray eel	Low	322.00	0.41	0.20	32.57	161.00	0.20	305.59	0.32	0.16	24.95	152.79

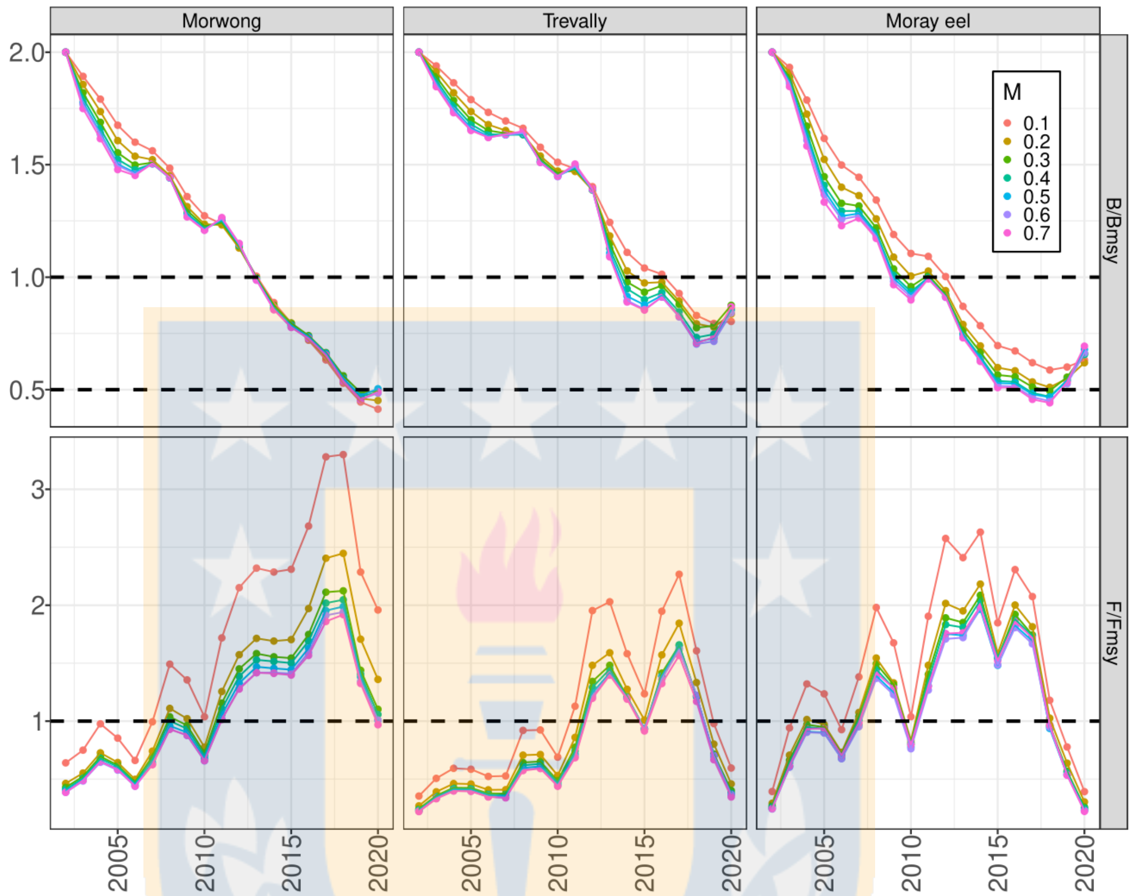

Figure S1. *Sensitivity of estimates of B/BMSY and F/FMSY to the use of different values of natural mortality (M) as input to the OCOM method for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel).*

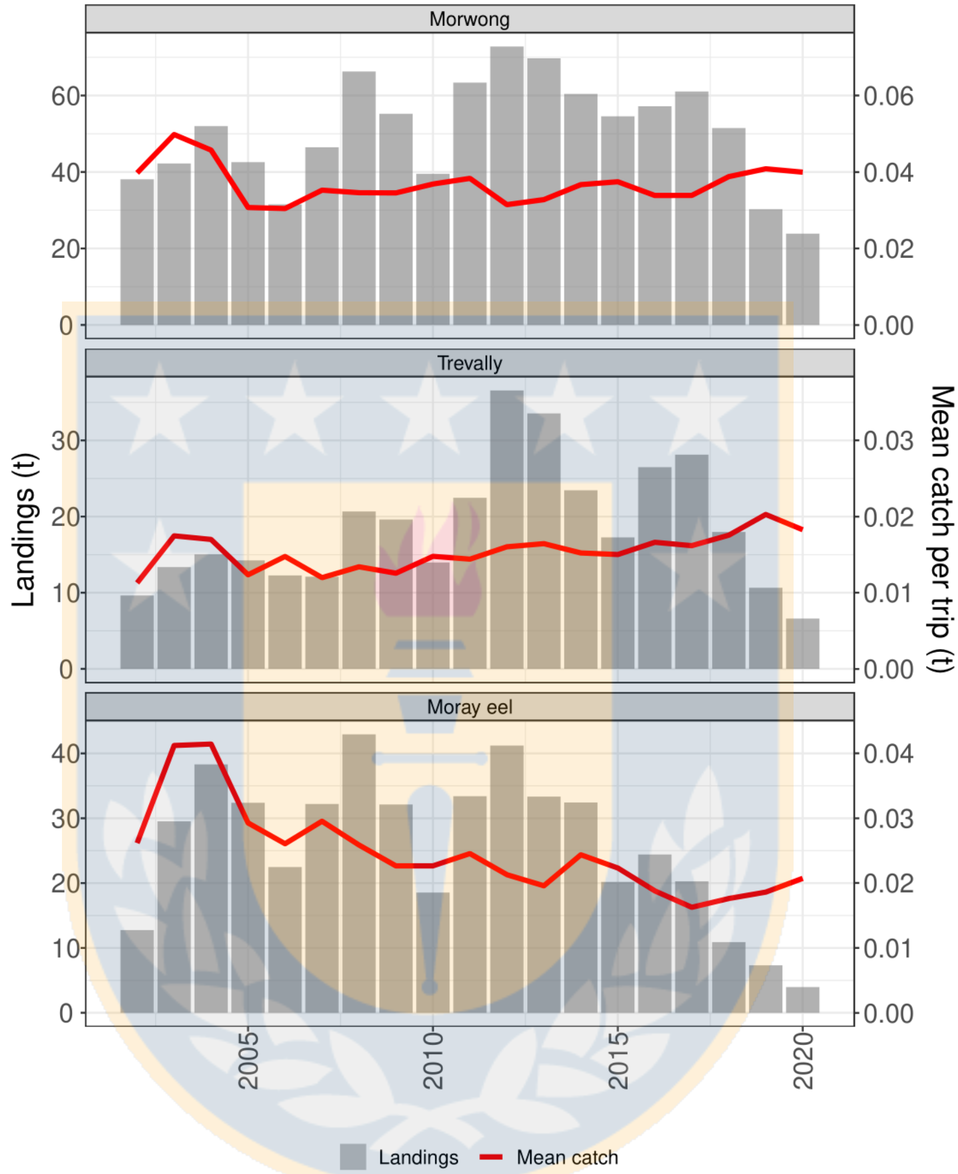

Figure S2. *Catch and average catches per trip in the period 2002-2020 for Nemadactylus gayi (morwong), Pseudocaranx chilensis (trevally) and Gymnothorax porphyreus (moray eel). Source SERNAPESCA.*

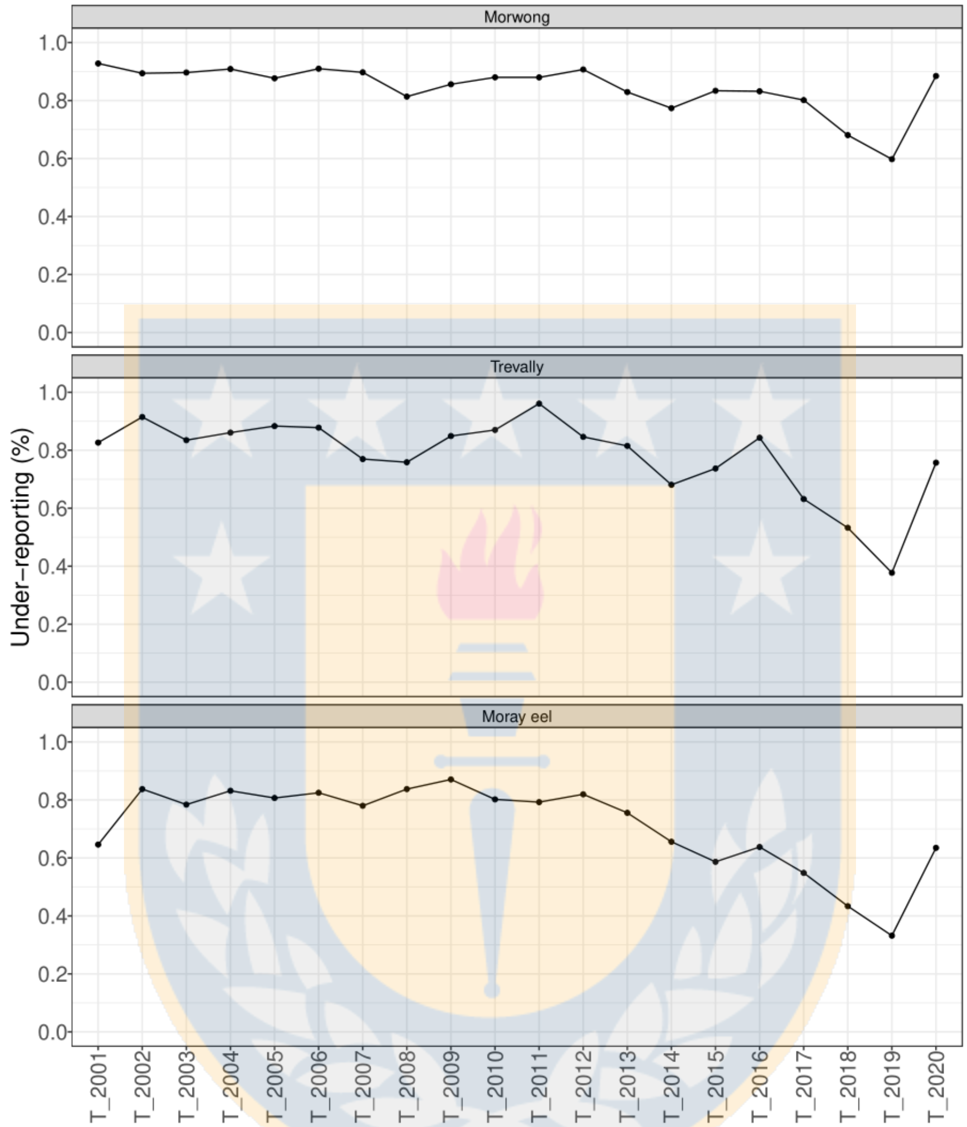

Figure S3. *Estimates of catch under-reporting in fisher's declarations to SERNAPESCA. Analysis based on the lobster fishing season assuming that each lobster trip must have necessarily declared bait species (fish) since they are necessary to harvest them. Values close to one expresses a low level of under-reporting.*

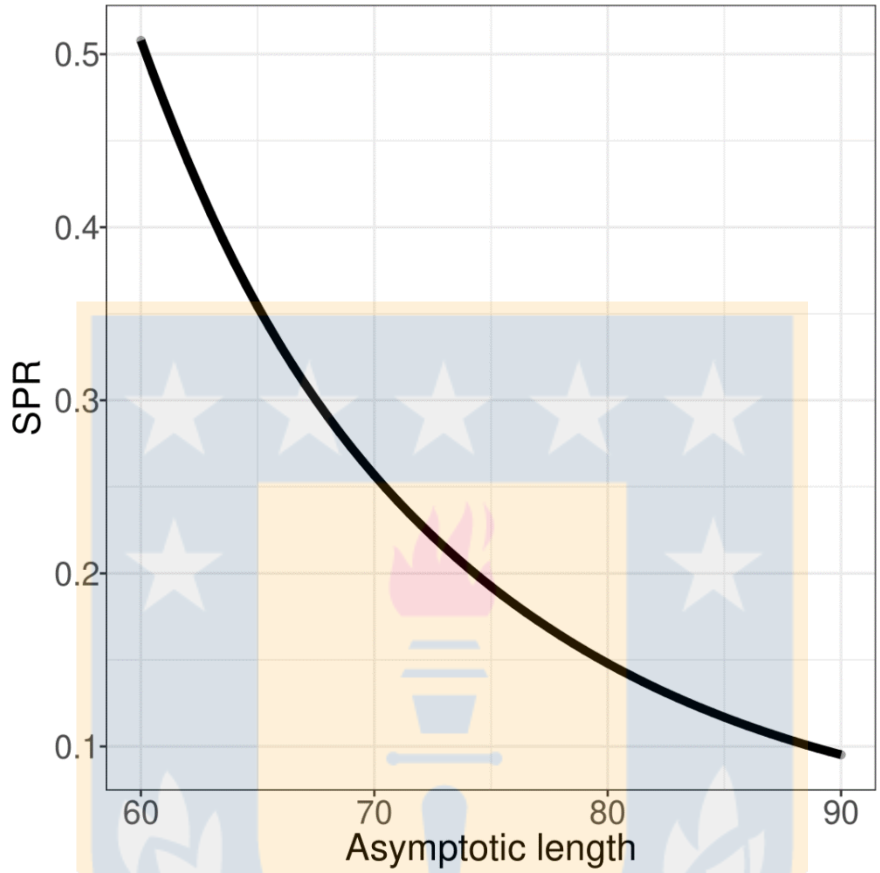

Figure S4. *Sensitivity analysis of LB-SPR with respect to asymptotic length of Nemadactylus gayi (morwong)*

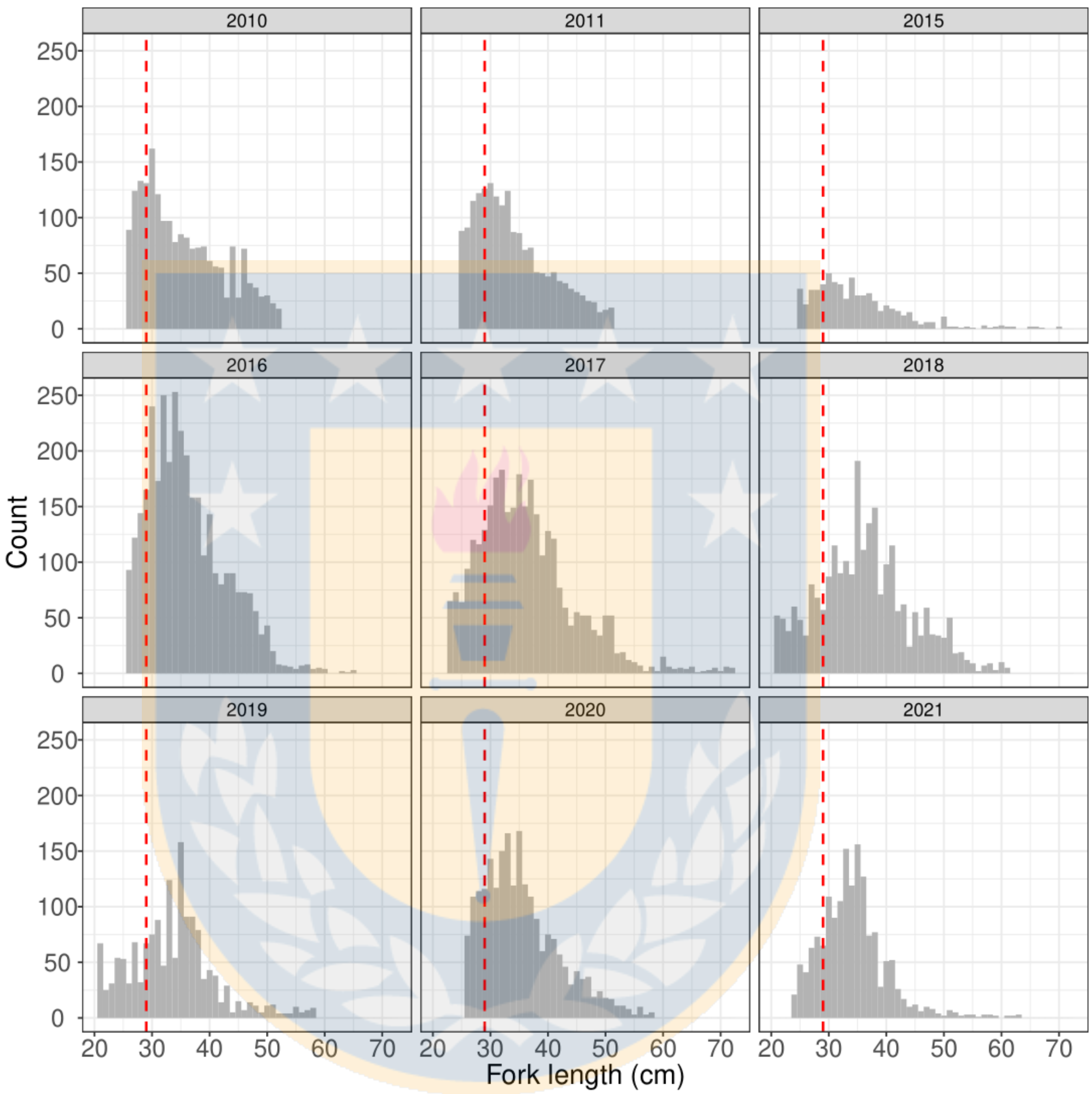

Figure S5. *Size frequency distribution for Nemadactylus gayi (morwong) between period 2010-2011 y and period 2015-2021. The red dotted line accounts for size of maturity (29 cm FL).*

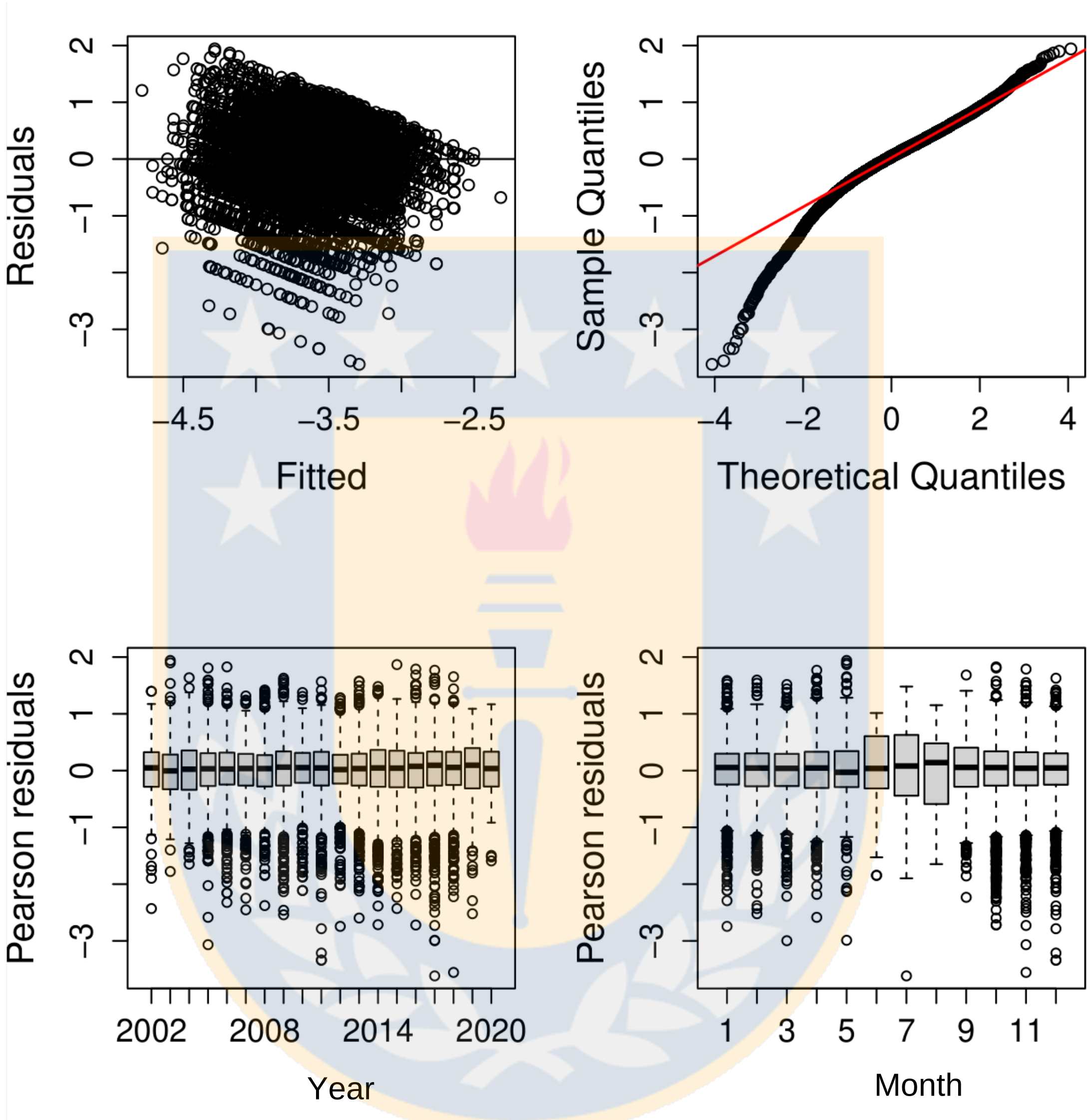

Figure S6. *Residuals-checking plots for the model used to standardized CPUE for Nemadactylus gayi. Source: SERNAPESCA*

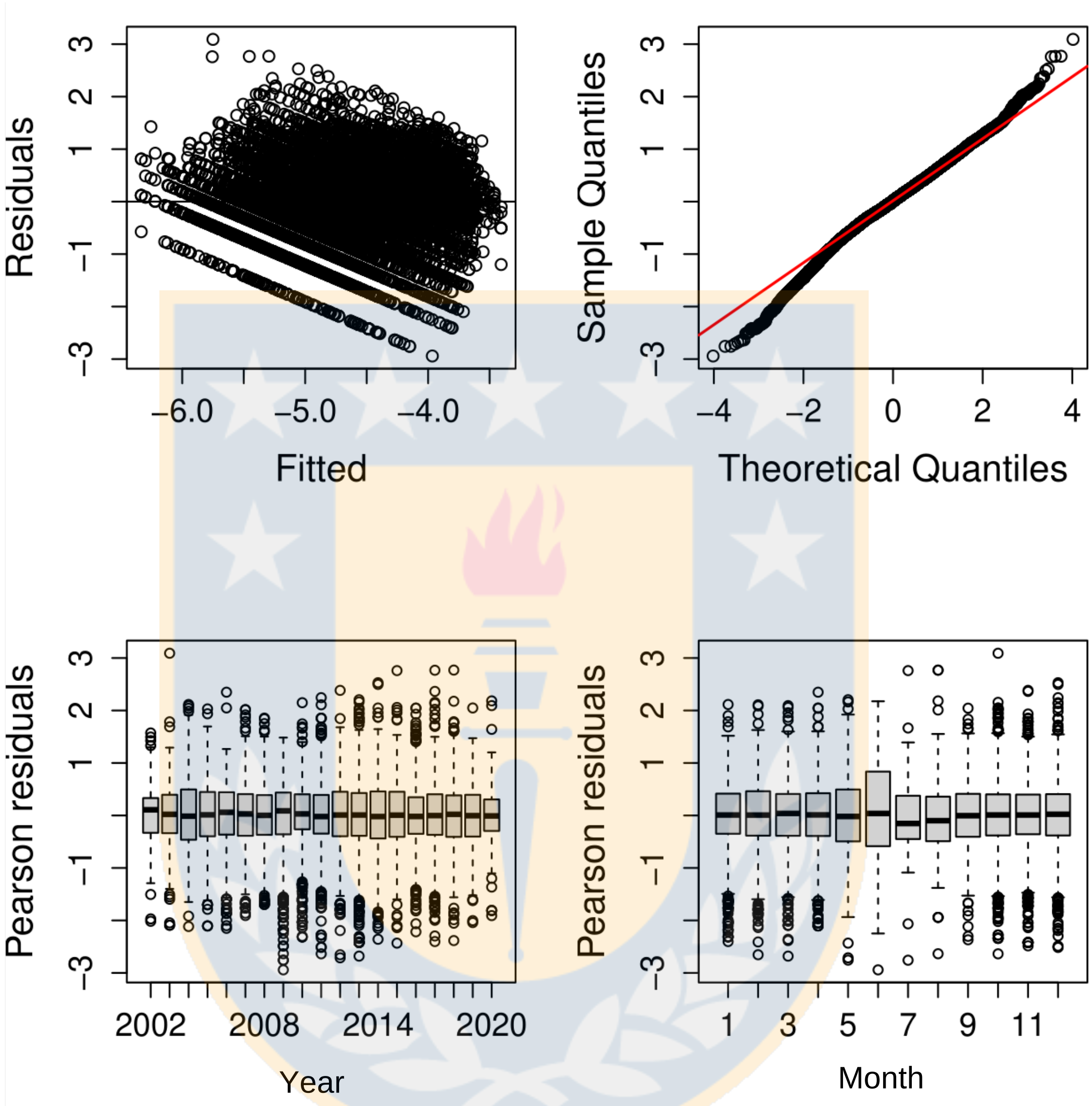

Figure S7. *Residuals-checking plots for the model used to standardized CPUE for Pseudocaranx chiliensis. Source: SERNAPESCA*

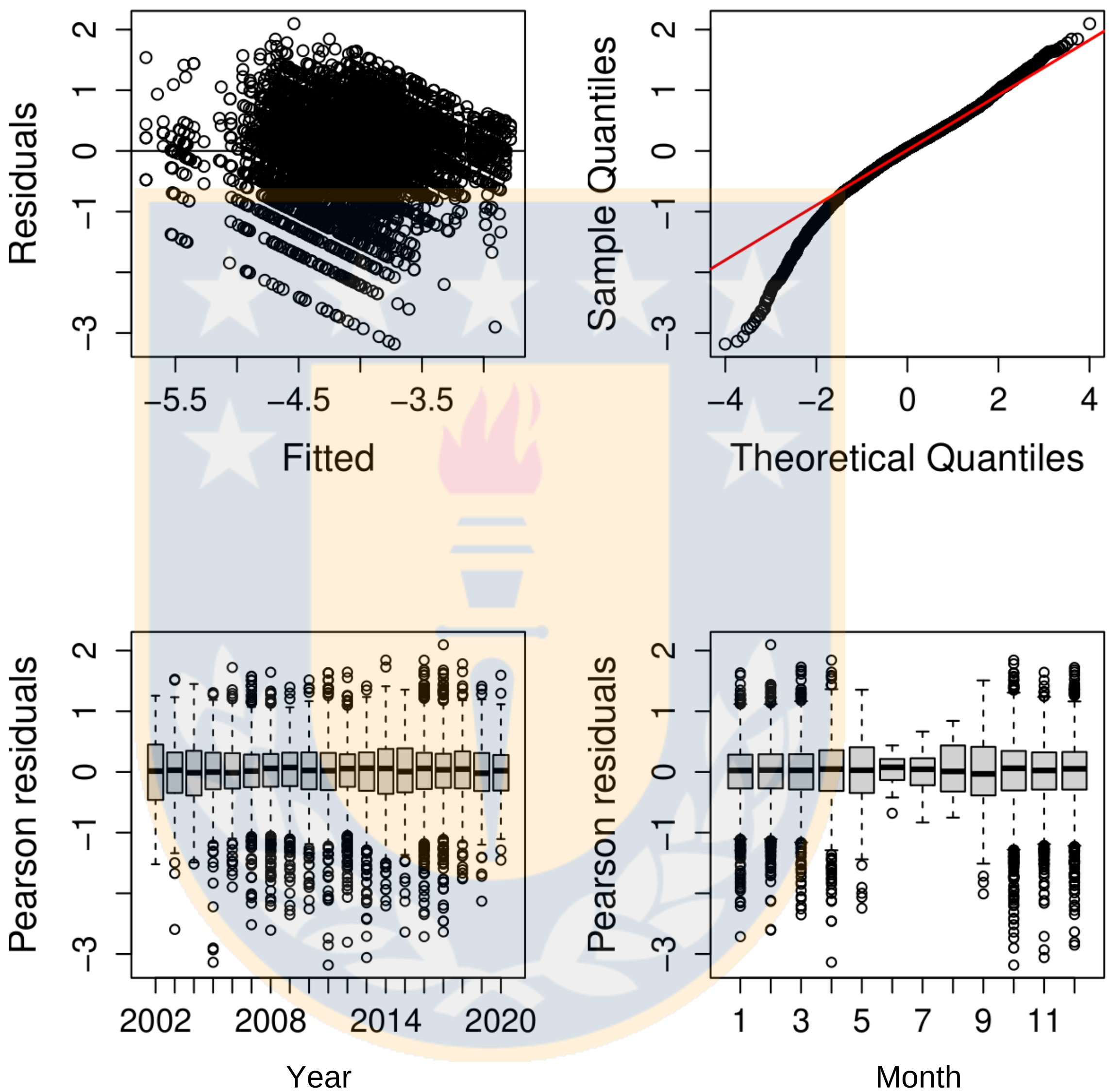

Figure S8. *Residuals-checking plots for the model used to standardized CPUE for Gymnothorax porphyreus. Source: SERNAPESCA*

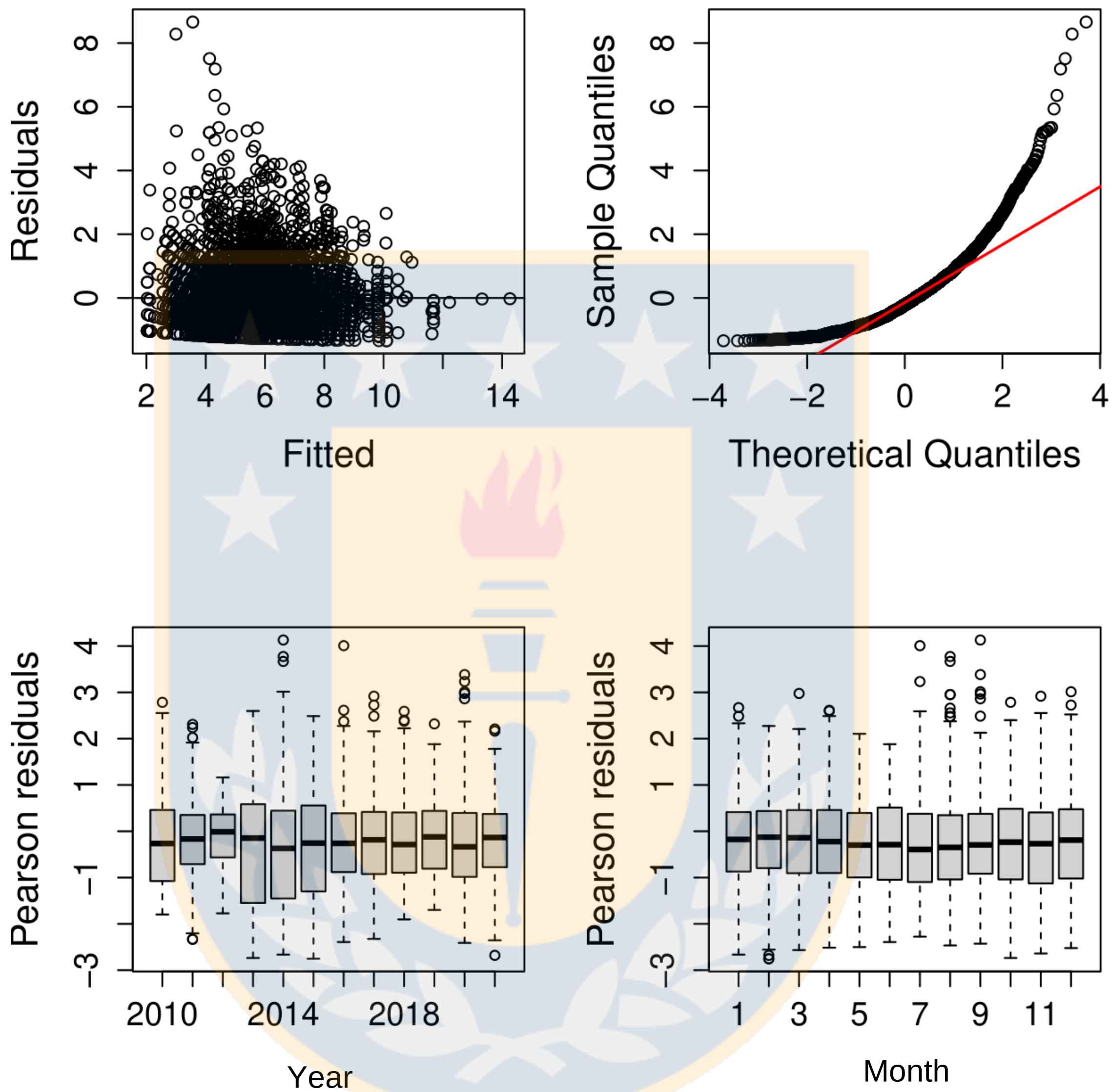

Figure S9. *Residuals-checking plots for the model used to standardized CPUE for Nemadactylus gayi. Source: Monitoring Program.*

DISCUSIÓN GENERAL

El presente estudio es el primer esfuerzo para evaluar el estado de los recursos ícticos empleados como carnadas en la pesquería de crustáceos de Juan Fernández mediante el uso de múltiples metodologías de evaluación en pesquerías con datos limitados. Estos recursos son de vital importancia para el buen funcionamiento de la pesquería de langosta (*Jasus frontalis*), la que provee el sustento económico de los residentes del archipiélago Juan Fernández. Pese a la importancia de las especies carnadas, el presente estudio puso en evidencia las escasas fuentes de información biológica-pesqueras disponibles para los recursos breca (*Nemadactylus gayi*), jurel de Juan Fernández (*Pseudocaranx chilensis*) y anguila-morena (*Gymnothorax porphyreus*); así como las limitaciones de las bases de datos reunidas por diferentes instituciones y/o proyectos de investigación para las especies mencionadas. Sin embargo, se destaca la continuidad y consistencia de sus registros.

Limitaciones en las fuentes de datos

La falta de consideración de distintas fuentes de información disponibles para una pesquería puede conllevar a conclusiones erróneas o incompletas. Por ejemplo, en la presente investigación hacer uso exclusivo de datos de captura pudo generar conclusiones incorrectas respecto al estado de los stocks de las especies carnadas. La búsqueda exhaustiva de datos y la comprensión de estos (e.g. forma en la que fueron colectados) resulta esencial para una correcta interpretación de los resultados. La inspección de otras fuentes de información como tallas, captura, esfuerzo y CPUE permitieron obtener una idea más amplia de la situación actual de los recursos explotados en el archipiélago Juan Fernández. Sin embargo, es importante mencionar las limitaciones y dificultades encontradas en las bases de datos. En primer lugar, la información biológica-pesquera en Juan Fernández provienen principalmente de dos programas de monitoreo: a) *bitácoras formales*, que registra los desembarques declarados por el pescador al SERNAPESCA y b) *Observadores a bordo*, que comprende la información colectada por personal calificado durante la temporada de captura de *J. frontalis*. Ambos monitoreos, aunque no han sido diseñados con el objetivo de hacer un seguimiento detallado de los recursos ícticos de Juan Fernández, contribuyen con información valiosa que se empleó en la elaboración de distintos indicadores de rendimiento pesquero. Sin embargo, resulta importante implementar un sistema de monitoreo orientado a los recursos ícticos que permita complementar la información biológica actual de peces en Juan Fernández. En segundo lugar, los registros biométricos para *P. chilensis* – por el modo operacional de la pesquería – corresponde sólo a la fracción juvenil de esta especie (Ernst et al., 2013b, Queirolo et al., 2011). Aunque no existen estudios formales en la distribución espacial de *P. chilensis* se ha observado que ejemplares juveniles de *P. dentex*, especie taxonómicamente relacionada con *P. chilensis*, tienen una marcada preferencia por los hábitats costeros, siendo lo opuesto para peces de mayor tamaño (Afonso et al., 2008; Masuda et al., 1995; Masuda y Tsukamoto, 1999). Este comportamiento podría asemejarse a *P. chilensis*. Los reportes indican que en las costas aledañas al archipiélago Juan Fernández se encuentran principalmente ejemplares de menor tamaño los cuales son capturados y usados en zonas más alejadas como carnada en la captura de ejemplares adultos de la misma especie (Ahumada y Queirolo et al., 2014). Para el caso de la anguila-morena, su comportamiento feroz y agresivo dificulta su medición biométrica por lo que los datos colectados para esta especie podrían tener un alto error de observación. Así mismo, los registros de captura corresponden a más de una especie de la familia muraenidae. No obstante, de acuerdo a conversaciones con investigadores del área, la principal especie de anguila-morena capturada en el subsistema Robinson Crusoe – Santa Clara correspondería a *Gymnothorax porphyreus*, la especie en estudio. Por último, la unidad del esfuerzo de pesca registrada en las bases de datos es muy general. La selección de la unidad del esfuerzo puede comprometer seriamente las tendencias de la CPUE reportadas aquí. Algunas alternativas a considerar en el corto plazo para complementar el actual sistema de levantamiento de información de peces, teniendo en cuenta que son pesquerías de bajo valor y en consecuencias de presupuesto limitado, sería desarrollar y ejecutar proyectos que permitan obtener información respecto al conocimiento ecológico local (LEK, por sus siglas en inglés), encuestas y/o investigaciones relacionadas en los aspectos biológicos, ecológicos y pesqueros. Las opciones mencionadas además de ser consideradas viables son alternativas costo-eficientes que pueden recabar información relevante que de otro modo resultaría difícil obtenerla durante las faenas de pesca.

Métodos de evaluación

Las múltiples metodologías de evaluación de stock con datos limitados no mostraron señales de sobreexplotación para la breca y el jurel, pero sí para la anguila morena. De acuerdo con estos resultados, se rechaza la hipótesis planteada en la presente investigación. No obstante, es importante mencionar que los resultados de los métodos empleados en el presente estudio pueden verse seriamente afectados por la falta de información biológica-pesquera específica de las especies evaluadas. Además, los importantes supuestos de cada metodología sugiere realizar investigaciones complementarias que permitan su validación. Por ejemplo, los métodos de captura asumen parámetros de productividad estacionarios (Zhou et al., 2018; Froese et al., 2017). Si bien estudios de la caracterización ambiental del sistema Juan Fernández durante el 2002-2017 no mostraron cambios importantes (Ernst et al., 2018), la relación de las variables ambientales con la productividad de los recursos evaluados es aún desconocida y comprometen la confiabilidad de los parámetros. Las limitadas capacidades para detectar cambios en la productividad o cambios de régimen ambiental es una de las principales debilidades de los métodos de captura, razón por la cual han sido ampliamente criticados (Bouch et al., 2020; Free et al., 2020; Ovando et al., 2021b, 2021a; Sharma et al., 2021). Por otro lado, la precisión y exactitud en la estimación de los parámetros de historia de vida desempeñan un rol fundamental en los métodos de evaluación de stocks. Estos fueron derivados de estudios de edad-crecimiento mediante lectura de otolitos que son considerados uno de los métodos más robustos. Sin embargo, durante el proceso de lectura se reportó para *P. chilensis* la presencia de falsos anillos, perturbaciones y discontinuidades que dificultaron su interpretación (Queirolo et al., 2011). Lo anterior puede derivar en sesgos importantes en la estimación de los parámetros de edad-crecimiento y, en consecuencia, en los resultados obtenidos por los métodos de evaluación empleados en este estudio. Por esta razón, es importante y necesario reevaluar los parámetros de historia de vida a fin de obtener valores de mayor confiabilidad.

El uso de los métodos para datos limitados tiene valor en identificar las especies en riesgo incluso si la evaluación no es suficientemente buena (Dowling et al., 2019). Así, estos métodos han sido empleados para establecer capturas biológicas aceptables (Newman et al., 2014, Cummings et al., 2016) o únicamente para determinar límites o indicios de sobre explotación para poblaciones de peces con datos limitados (Dowling et al., 2015, Fitzgerald et al., 2018, Ramírez-Gonzáles et al., 2018; Vahabnezhad et al., 2021). Sin embargo, es importante mencionar que la presente investigación no propone reemplazar las metodologías tradicionales de evaluación de stocks, ya que se conocen que éstas son más precisas y confiables, sino que la aplicación de estos métodos se vuelven relevantes en un contexto donde no se cuenta con información suficiente y los métodos tradicionales se ven limitados. La importancia de los métodos de captura y tallas empleados en el presente estudio radica en obtener puntos de referencias iniciales sobre la cual se puedan plantear medidas de manejo preliminares mientras se van realizando protocolos de colecta de datos para su uso posterior en metodologías más robustas.

Medidas de manejo

Durante ya algunos años el comité de manejo de Juan Fernández ha venido trabajando en la elaboración de un “Plan de Manejo Pesquero” apropiado para sus pesquerías. En este documento se han abordado los diferentes aspectos del ámbito pesquero tales como: a) aspectos biológico-pesquero, b) ecológico-ambiental, c) ambiental, d) económico y e) social. Dentro de los aspectos biológico-pesquero se ha propuesto como meta asegurar la sustentabilidad de las pesquerías de crustáceos y su fauna asociada, la cual comprende a diversas especies ícticas como breca, anguila, jurel de Juan Fernández, entre otras. En el caso particular de la pesquería de crustáceos, se disponen de algunos elementos que permitieron construir indicadores empíricos, puntos de referencia, reglas de control y mecanismos de acción frente a indicios de sobre explotación, los mismos que han sido incluidos dentro de la propuesta del plan de manejo de Juan

Fernández. Sin embargo, para las pesquerías de peces no existían tales elementos; en consecuencia, la elaboración de medidas de manejo para los recursos ícticos del archipiélago a la fecha se vio limitada.

Los puntos biológicos de referencia son de particular interés para el manejo pesquero. En la presente investigación, los valores de B_{MSY}, F_{MSY} y MSY fueron estimados únicamente mediante los métodos de captura. Sin embargo, el nivel de subreporte – que aumentó en los últimos años – comprometió la estimación de los puntos biológicos de referencia basados en la biomasa o MSY. Por esta razón, los valores reportados deben ser usados con precaución y complementados con un buen procedimiento de manejo. Solamente bajo estas condiciones podrían ser usados como un punto de partida para desarrollar recomendaciones de manejo. Aunque no se ha recomendado intervenciones específicas de manejo para las pesquerías de breca, jurel de Juan Fernández y anguila-morena animamos a adoptar un enfoque proactivo para participar en un proceso de planificación de la gestión con el fin de abordar los principales resultados reportados aquí. Se espera que esta investigación pueda contribuir a las iniciativas mostradas por el sector público y privado al comité de manejo de Juan Fernández para el desarrollo de un plan de manejo de los recursos ícticos de la localidad.

CONCLUSIONES

- Es posible detectar indicios de agotamiento en las poblaciones objetivos a partir de un conjunto de técnicas de evaluación limitadas en datos.
- Se detectaron indicios de agotamiento para el stock de anguila, pero no para los stocks de breca y jurel de Juan Fernández.
- El conocimiento del modo operacional de la flota artesanal en Juan Fernández y el entendimiento de los supuestos de cada metodología de evaluación limitada en datos resulta de vital importancia en la selección e implementación de los métodos de evaluación de stocks.
- Cuantificar el nivel de sub-reporte es de vital importancia en la clasificación del estado de los stocks mediante metodologías basadas sólo en datos de capturas.
- Las mejoras en la evaluación de los recursos objetivos dependerán de una recopilación ampliada de datos específicos para cada pesquería.

BIBLIOGRAFÍA

Aburto J., Gaymer C., Haoa S., Gonzáles L. (2015). Management of marine resources through a local governance perspective: Re-implementation of traditions for marine resource recovery on Easter Island. Ocean & Coastal Management 116, 108-115.

Afonso, P., Fontes, J., Morato, T., Holland, K., & Santos, R. (2008). Reproduction and spawning habitat of white trevally, pseudocaranx dentex, in the azores, central north atlantic [Journal Article]. Scientia Marina, 72, 373–381.

Ahumada, M., y Queirolo, D. (2014). Fish exploitation associated to the artisanal fishing of Juan Fernándezlobster (Jasus frontalis) | Explotación de peces asociada a la pesquería artesanal de langosta de Juan Fernández (Jasus frontalis). Latin American Journal of Aquatic Research, 42(1), 213–223. https://doi.org/103856/vol42-issue1-fulltext-18

Arana, P. (ed.). (2012). Recursos pesqueros del mar de Chile. Escuela de Ciencias del Mar, PUCV, Valparaíso, 308pp

Arana, P., Palma, S., Guerrero, A., Ahumada, M., y Jofré, A. (2006). Monitoreo biológico-pesquero de la langosta y cangrejo dorado en el archipiélago de juan fernández. Valparaíso, Chile.

Bouch, P., Minto, C., Reid, D., 2020. Comparative performance of data-poor CMSY and data-moderate SPiCT stock assessment methods when applied to data-rich, real-world stocks. ICES Journal of Marine Science 78. doi:10.1093/icesjms/fsaa220

Carruthers T., Punt A., Walters C., MacCall A., MacAllister M., Dick E., Cope J. (2014). Evaluating methods for setting catch limits in data-limited fisheries. Fisheries Research 153 (2014) 48-68. http://dx.doi.org/10.1016/j.fishres.2013.12.014

Costello C., Ovando D., Hilborn R., Gaines S., Deschenes O., Lester S. (2012). Status and Solutions for the World's Unassessed Fisheries. Science 338, 517-520.

Cummings, N., Sagarese, S., Huynh, Q.C., 2016. An alternative approach to setting annual catch limits for data-limited fisheries: Use of the DLMtool and mean length estimator for six US Caribbean stocks. SEDAR46-RW-03. North Charleston, SC.

Declaración de Río sobre el Medio Ambiente y el Desarrollo (1992). Principio 15. https://www.un.org/spanish/esa/sustdev/agenda21/riodeclaration.htm

Dowling N., Smith A., Smith D., Parma A, Dichmont C., Sainsbury K., Wilson J., Dougherty D., Cope J. (2019). Generic Solutions for data-limited fishery assessments are not so simple. Fish and Fisheries. 2018; 00:1-15. https://doi.org/10.1111/faf.12329

Dowling N., Wilson J., Rudd M., Badcock E., Caillaux M., Cope J., Dougherty D., Fujita R., Gedamke T., Gleason M., Gutierrez N., Hordyk A., Maina G., Mous P., Ovando D., Parma A., Prince J., Revenga C., Rude J., Szuwalski C., Valencia S., Steven V. (2016). FishPath: A Decision Support System for Assessing and Managing Data – and Capacity- Limited Fisheries. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks. http://doi.org/10.4027/amdlfs.2016.03

Dowling, N.A., Dichmont, C.M., Haddon, M., Smith, D.C., Smith, A.D.M., Sainsbury, K., 2015. Empirical harvest strategies for data-poor fisheries: A review of the literature. Fisheries Research, Development, testing, and evaluation of data-poor assessment and fisheries management methods 171, 141–153. doi:10.1016/j.fishres.2014.11.005

Eddy, T. D., Gardner, J. P. A., y Pérez-Matus, A. (2010). Applying Fishers' Ecological Knowledge to Construct Past and Future Lobster Stocks in the Juan Fernandez Archipelago, Chile. PLoS ONE, 5(11). https://doi.org/10.1371/journal.pone.0013670

Ernst, B., Chamorro J., Manríquez, P., Orensanz J., Parma A., Porobic J., Román C. (2013a). Sustainability of the Juan Fernández lobster fishery (Chile) and the perils of generic science-based prescriptions. Global Environmental Change, 1381-1392, 23(6).

Ernst, B., Orensanz, J.M., Manriquez, P., Chamorro, J., Roman, C., Porobic, J., y Rivara, P. (2012). Monitoreo a la pesquería de crustáceos en el archipiélago Juan Fernández, año 2011” (Proyecto N°4728-36-LP12).

Ernst, B., Parada, C., Chamorro, J., Manríquez, P., Pino, J., Tapia, B., Sandoval, M., 2018. Programa de seguimiento de las principales pesquerías nacionales, año 2017. Pesquerías de Crustáceos del archipiélago Juan Fernández. Universidad de Concepción, Concepción.

Ernst, B., Salas, E., Porobic, J., Román, C., Chamorro, J., Manríquez, P., Pérez, M., Schiller, R., Recabarren, S., Contreras, A., Melgarejo, M., Chamorro, M., Schiller, H., Schiller, O., Lemus, R., Mieres, M. (2013b). Monitoreo de las principales pesquerías del archipiélago Juan Fernández, año 2012. Proyecto FIP N° 4728-36 LE12. Concepción - Chile.

Ernst, Billy, Manríquez, P., Orensanz, J. M., Roa, R., Chamorro, J., y Parada, C. (2010). Strengthening of a traditional territorial tenure system through protagonism in monitoring activities by lobster fishermen from the Juan Fernández islands, Chile. Bulletin of Marine Science, 86(2), 315–338.

Ernst, Billy, Oyarzún, C., Vilches, J., Pablo, R., Tapia, B., Alvarez, C., Molina, E., Leiva, F., Gauthier, S. (2016a). Estudio ecosistémico de las pesquerías del sitio piloto archipiélago de juan fernández. Fase metodológica. Proyecto: GEF-UNDP Hacia un Manejo Ecosistémico del Gran Ecosistema Marino de la Corriente de Humboldt (GEMCH) – PIMS 4147 Concepción - Chile.

Ernst, Billy, Pino, J., Chamorro, J., Manriquez, P., y Rivara, P. (2016b). Programa de Seguimiento de las Principales Pesquerías Nacionales, año 2015. Pesquerías de Crustáceos del archipiélago Juan Fernández. Concepción - Chile.

Fitzgerald, S.P., Wilson, J.R., Lenihan, H.S., 2018. Detecting a need for improved management in a data-limited crab fishery. Fisheries Research 208, 133–144. doi:10.1016/j.fishres.2018.07.012

Free, C.M., Jensen, O.P., Anderson, S.C., Gutierrez, N.L., Kleisner, K.M., Longo, C., Minto, C., Osio, G.C., Walsh, J.C., 2020. Blood from a stone: Performance of catch-only methods in estimating stock biomass status. Fisheries Research 223, 105452. doi:10.1016/j.fishres.2019.105452

Friedlander AM, Ballesteros E, Caselle JE, Gaymer CF, Palma AT, Petit I, et al. (2016). Marine Biodiversity in Juan Fernández and Desventuradas Islands, Chile: Global Endemism Hotspots. PLoS ONE 11(1): e0145059. doi:10.1371/journal. pone.0145059

Froese, R., Demirel, N., Coro, G., Kleisner, K., Winker, H., 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries 18, 506–526. doi:10.1111/faf.12190

Gaymer, C., Aburto, J., Acuña, E., Bodini, A., Carcamo, F., et al., 2013. Base de conocimiento y construcción de capacidades para el uso sustentable de los ecosistemas y recursos marinos de la ecorregión de Isla de Pascua. Licitación 4728- 33-le12. Subsecretaría Pesca, p. 191.

Godoy N., Gelcich S., Castilla J., Mauricio L., Smith A. (2016). Artisanal Spearfishery in Temperate Nearshore Ecosystems of Chile: Exploring the Catch Composition, Revenue, and Management Needs. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 8:436-447. 10.1080/19425120.2016.1185062

Godoy N., Gelcich S., Vásquez J., Castilla J (2010). Spearfishing to depletion: evidence from temperate reef fishes in Chile. Ecological Applications, 20 (6), pp. 1504 – 1511.

Godoy Natalio (2013). Pesquería artesanal por buceo de peces de roca en el centro norte de Chile: Diagnóstico del sistema social-ecológico y los desafíos para su sustentabilidad. Tesis de doctorado. Facultad de Ciencias Biológicas de la Pontificia Universidad Católica de Chile. Santiago de Chile.

Mann G. (1954). La vida de los peces en aguas chilenas. Ministerio de Agricultura, Instituto de Investigaciones Veterinarias y Universidad de Chile. Santiago de Chile. 343pp.

Manriquez P. (2016). Crecimiento somático de la langosta de Juan Fernández

Jasus frontalis (H. Milne Edwards, 1837) y evaluación del impacto de la talla mínima legal de extracción como táctica del manejo de su pesquería. Universidad de Concepción.

Masuda, R., & Tsukamoto, K. (1999). School formation and concurrent developmental changes in carangid fish with reference to dietary conditions [Journal Article]. Environmental Biology of Fishes, 56(1), 243–252. https://doi.org/10.1023/A:1007565508398

Masuda, R., Kamaishi, T., Kobayashi, T., Tsukamoto, K., & Numachi, K. (1995). Mitochondrial DNA differentiation between two sympatric morphs of striped jack near Japan [Journal Article]. Journal of Fish Biology, 46(6), 1003–1010. https://doi.org/10.1111/j.1095-8649.1995.tb01405.x

McCosker, J. y Béarez, P. 2010. Gymnothorax porphyreus. The IUCN Red List of Threatened Species 2010: e.T183859A8189838. http://dx.doi.org/10.2305/IUCN.UK.2010-3.RLTS.T183859A8189838.en

McDonald G., Carcamo R., Fujita R., Gedamke T., Karr K., Wilson J. (2014). A Multi-indicator Framework for Adaptative Management of Data-limited Fisheries with a case of study from Belize. 67th Gulf and Caribbean Fisheries Institute November 3 – 7.

Newman, D., Carruthers, T., MacCall, A., Porch, C., Suatoni, L., 2014. Improving the science and management of data-limited fisheries: An evaluation of current methods and recommended approaches. Natural Resources Defense Council, NRDC report R 14–09.

Ovando, D., Free, C.M., Jensen, O.P., Hilborn, R., 2021a. A history and evaluation of catch-only stock assessment models. Fish and Fisheries n/a. doi:10.1111/faf.12637

Ovando, D., Hilborn, R., Monnahan, C., Rudd, M., Sharma, R., Thorson, J.T., Rousseau, Y., Ye, Y., 2021b. Improving estimates of the state of global fisheries depends on better data. Fish and Fisheries 22, 1377–1391. doi:10.1111/faf.12593

Pequeño, G., y Sáez, S. (2000). Los peces litorales del Archipiélago Juan Fernández (Chile): endemismo y relaciones ictiogeográficas. Investigaciones Marinas., 28: 27-37.

Pladeco. 2009. Plan de desarrollo Comunal. Obtenido desde la página web http://www.munivalpo.cl/transparencia/archivos/plan_desarrollo_comunal/PLADECO.pdf

Prince J, Victor S., Hordyk A. (2015). Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. Fisheries Research 171 (2015) 42-58. DOI: 10.1016/j.fishres.2015.06.008

Queirolo, D., Ahumada, M., Plaza, G., Saavedra, J., Arana, P., Escobar, R., Merino, J., Gaete, E., Vivanco, M., Ruby, R., 2011. Alternativas de carnada en la pesquería de langosta de Juan Fernández (Jasus frontalis), para disminuir el impacto sobre especies ícticas del archipiélago (FIP 2009-31). Pontificia Universidad Católica de Valparaíso, Valparaíso - Chile.

Ramirez-González, J., Banda-Cruz, G., Moreno, J., Ovando, D., Reyes, H., Rosero, P., Timpe, I., 2018. Implementation of a multiple indicator system for fisheries with limited information in a context of co-management, case study: Spiny lobster fishery in the Galapagos Marine Reserve. Ocean & Coastal Management 154, 20-25. doi:10.1016/j.ocecoaman.2017.12.027

Rozbaczylo y Castilla, 1987. Rozbaczylo, N., y Castilla, J. (1987). Invertebrados marinos del Archipiélago Juan Fernández. In: Castilla J.C. (ed) Islas Oceánicas Chilenas: Conocimiento Científico y Necesidades de Investigaciones. Ediciones Universidad Católica de Chile. 319-353 pp.

Servicio Nacional de Pesca y Acuicultura, 2020a. Anuario Estadístico de Pesca y Acuicultura 2020. Desembarques y Acuicultura. Desembarque industrial y artesanal por especie y mes. URL: http://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

Servicio Nacional de Pesca y Acuicultura, 2020b. Anuario Estadístico de Pesca y Acuicultura 2020. Desembarques y Acuicultura. Desembarque total. URL: http://www.sernapesca.cl/informacion-utilidad/anuarios-estadisticos-de-pesca-y-acuicultura

Sharma, R., Winker, H., Levontin, P., Kell, L., Ovando, D., Palomares, M.L.D., Pinto, C., Ye, Y., 2021. Assessing the Potential of Catch-Only Models to Inform on the State of Global Fisheries and the UN's SDGs. Sustainability 13, 6101. doi:10.3390/su13116101

Subsecretaría de Pesca y Acuicultura, 2021. Estado de situación de las principales pesquerías chilenas, año 2019. URL: http://www.subpesca.cl/portal/618/w3-article-107314.html

Tapia, B., Gauthier, S., Ernst, B., Molina, E., Rivara, P., & Leiva, F. (2017, 25-27 July 2017). Characteristics and distribution of coastal fish schools around Robinson Crusoe Island (Juan Fernandez Archipelago, Chile). Paper presented at the 2017 IEEE/OES Acoustics in Underwater Geosciences Symposium (RIO Acoustics).

The Nature Conservancy (2019). Peces Litorales de Chile. Guía para una pesca recreativa marina sustentable. Santiago de Chile.

Vahabnezhad, A., Hashemi, S. A., Taghavimotlagh, S. A., & Daryanbard, G. (2021). Length based spawning potential ratio (LBSPR) of javelin grunter, Pomadasys kaakan (Cuvier, 1830) in the Persian Gulf and Oman Sea. Iranian Journal of Fisheries Sciences, 20(6), 1560-1572.

Zhou, S., Punt, A.E., Smith, A.D.M., Ye, Y., Haddon, M., Dichmont, C.M., Smith, D.C., 2018. An optimized catch-only assessment method for data poor fisheries. ICES Journal of Marine Science 75, 964–976. doi:10.1093/icesjms/fsx226