UNIVERSIDAD AUTÓNOMA DE BAJA CALIFORNIA
FACULTAD DE CIENCIAS MARINAS
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MAESTRÍA EN CIENCIAS EN OCEANOGRAFÍA COSTERA

EL MANEJO EFICIENTE DE LOS DERECHOS DE USO TERRITORIAL PARA LA PESCA CONTRIBUYE A LA CONSERVACIÓN DE ESPECIES DE IMPORTANCIA COMERCIAL

WELL-MANAGED TERRITORIAL USE RIGHTS FOR FISHERIES ENHANCE CONSERVATION BENEFITS FOR TARGETED SPECIES

TESIS

QUE PARA CUBRIR PARCIALMENTE LOS REQUISITOS NECESARIOS PARA
OBTENER EL GRADO DE MAESTRA

PRESENTA

JESSICA ANAYANSI GARCIA PANTOJA

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RESUMEN (Español)

Los Derechos de Uso Territorial para la Pesca (TURFs, por sus siglas en inglés) son promovidos cada vez más como herramientas de manejo espacial de base comunitaria con el potencial de fortalecer tanto las pesquerías de pequeña escala como la conservación de la biodiversidad. No obstante, su desempeño ecológico varía ampliamente en función de la efectividad de su gobernanza. En la península de Baja California, el kelp gigante *Macrocystis pyrifera* estructura los ecosistemas de bosques de kelp y sostiene pesquerías costeras que se manejan principalmente a través de un mosaico de TURFs. En este estudio evaluamos si los TURFs bien manejados mejoran los resultados de conservación para invertebrados de importancia comercial y peces arrecifales a lo largo de ~800 km de costa. Utilizamos información espacial de TURFs para langosta (*Panulirus interruptus*), abulón (*Haliotis* spp.), erizo rojo (*Mesocentrotus franciscanus*), caracol (*Megastraea* spp.) y pepino de mar (*Apostichopus parvimensis*), obtenida de CONAPESCA, junto con monitoreos submarinos anuales realizados entre 2022 y 2024 en 32 sitios de bosques de kelp. Los sitios se clasificaron en tres tipos de TURFs: Concesión (un solo titular de largo plazo y bien manejado), Permiso (un solo titular de corto plazo) o Mixto (coexistencia de concesionarios y permisionarios), con base en el traslape espacial y en atributos de gobernanza a escala local, como vigilancia, monitoreo y participación comunitaria. En general, encontramos que los TURFs bien manejados incrementan la biomasa de especies de importancia comercial, aunque los patrones agregados para invertebrados explotados fueron menos claros. La biomasa total de invertebrados fue menor en los TURFs bien manejados en comparación con los sitios de Permiso o Mixtos, principalmente por la contribución desproporcionada del erizo rojo en sitios del norte, caracterizados por una débil aplicación de las regulaciones pesqueras. Sin embargo, los análisis a nivel de especie mostraron efectos de manejo fuertes y consistentes dentro de los TURFs. La biomasa de abulón y langosta fue entre 8 y 150 veces mayor en los TURFs bien manejados, mientras que fue cercana a cero en los sitios de Permiso y Mixtos. De manera similar, la biomasa total de peces y de especies clave explotadas, como la vieja Californiana (*Bodianus pulcher*) y la cabrilla (*Paralabrax clathratus*), fue entre 2 y 14 veces mayor en los TURFs bien manejados que en las otras categorías de sitios. Aunque la composición de la comunidad mostró una transición biogeográfica marcada a lo largo de la península, las especies con centroides de distribución en la región central respondieron principalmente al manejo y no a la latitud, lo que sugiere que los gradientes latitudinales no explican los patrones de abundancia observados. Por lo tanto, estos resultados evidencian que los beneficios ecológicos dependen fuertemente de una gobernanza local efectiva y resaltan el potencial de los TURFs bien manejados para contribuir a la conservación como Otras Medidas Efectivas de Conservación Basadas en Áreas (OECMs), apoyando las metas 30×30 y las estrategias nacionales de restauración en contextos donde los derechos espaciales comunitarios sostienen las pesquerías y los medios de vida locales.

Palabras clave: Manejo espacial; Derechos de Uso Territorial Para la Pesca (TURFs); Pesquerías de pequeña escala; Biodiversidad de Bosques de kelp; Recursos marinos bentónicos; México.

ABSTRACT

Territorial Use Rights for Fisheries (TURFs) are increasingly promoted as community-based spatial management tools that can support both small-scale fisheries and biodiversity conservation, yet their ecological performance varies widely with governance effectiveness. Along the Baja California Peninsula, the giant kelp *Macrocystis pyrifera* structures kelp forest ecosystems and sustains coastal fisheries that are managed primarily through a mosaic of TURFs. Here, we evaluate whether well-managed TURFs enhance conservation outcomes for commercially important invertebrates and reef fishes across ~800 km of coastline. We used spatial information on TURFs for spiny lobster (*Panulirus interruptus*), abalone (*Haliotis* spp.), red sea urchin (*Mesocentrotus franciscanus*), sea snail (*Megastraea* spp.), and sea cucumber (*Apostichopus parvimensis*) obtained from CONAPESCA, and conducted annual underwater surveys from 2022 to 2024 at 32 kelp forest sites. Sites were classified into three types of TURFs: Concession (a well-managed single long-term holder), Permit (a single short-term holder), or Mixed (coexisting concession and permit holders) based on spatial overlap and expert knowledge of site-level governance attributes, including surveillance, monitoring, and local engagement. Overall, we found that well-managed TURFs enhance the biomass of commercially important species, although aggregate patterns for harvested invertebrates were less clear. Total invertebrate biomass was lower in well-managed TURFs compared to Permit or Mixed sites, largely due to the disproportionate contribution of red sea urchins in northern sites characterized by weak enforcement of fisheries regulations. However, species-specific analyses revealed strong and consistent management effects within TURFs. Biomass of abalone and spiny lobster was 8–150 times higher in well-managed TURFs, while was near zero in Permit and Mixed sites. Total fish biomass and biomass of key harvested species, including the California sheephead (*Bodianus pulcher*) and kelp bass (*Paralabrax clathratus*), were 2–14 times higher in well-managed TURFs than in the other site categories. Although community composition exhibited a pronounced biogeographic transition along the peninsula, species whose distributional centroids overlap the central portion of the study region responded primarily to management rather than latitude, suggesting that latitudinal gradients do not underlie the observed abundance patterns. Together, these results demonstrate that ecological outcomes depend strongly on effective local governance and highlight the potential for well-managed TURFs to deliver substantial conservation benefits as Other Effective Area-based Conservation Measures (OECMs), contributing to 30×30 targets and national restoration strategies in regions where community-based spatial rights underpin local livelihoods and fisheries governance.

Key words: Spatial management; Territorial use rights for fisheries (TURFs); Small-scale fisheries; Kelp Forest biodiversity; Benthic marine resources; Mexico.

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1. INTRODUCCIÓN (Español)

La pesca ha sido durante mucho tiempo una de las actividades humanas más importantes para el sustento de las comunidades costeras a nivel global. En la actualidad, las pesquerías de pequeña escala (PPE), que representan más del 90% de la fuerza laboral pesquera global, aportan cerca de la mitad de la captura total de peces en el mundo (Basurto et al., 2025; FAO et al., 2023). Estas pesquerías son fundamentales para la seguridad alimentaria, el empleo y la identidad cultural en numerosas regiones costeras (Canty & Deichmann, 2022; Short et al., 2021). Sin embargo, en ausencia de un manejo pesquero efectivo, la sobrepesca está impulsando la pérdida de biodiversidad, erosionando la resiliencia de los ecosistemas marinos frente a los impactos climáticos y, en última instancia, amenazando los medios de vida de las comunidades costeras (Kumagai et al., 2024; Coll et al., 2010; Coleman & Williams, 2002). Para enfrentar estos desafíos, los esfuerzos globales de conservación buscan proteger y restaurar de manera efectiva el 30 % de los océanos para 2030, garantizando al mismo tiempo el uso sostenible de los recursos (Convention of Biological Diversity, 2021).

Las Áreas Marinas Protegidas (AMP) han sido una de las herramientas de conservación más ampliamente adoptadas y mejor documentadas a nivel global. Las AMP bien manejadas y con alto cumplimiento, especialmente aquellas bajo esquemas de protección estricta sin extracción, pueden incrementar la diversidad de especies, la biomasa de peces, la producción reproductiva y la resiliencia de los ecosistemas frente a los impactos climáticos (Olguin Jacobson et al., 2025; Kumagai et al., 2024; Lubchenco & Grorud-

Colvert, 2015; Micheli et al., 2012). A pesar de estos beneficios, las AMP altamente protegidas cubren actualmente solo el 3.1 % de los océanos del mundo (MPA Atlas, 2025). Las AMP también se han utilizado como herramientas de manejo pesquero, especialmente cuando se establecen como reservas de base comunitaria (Smallhorn-West et al., 2020; Villaseñor-Derbez et al., 2019). No obstante, cuando las AMP no se crean mediante enfoques participativos, pueden generar conflictos con las comunidades locales que dependen directamente de los recursos marinos para su subsistencia, limitando así su efectividad (Jiang et al., 2024; Ferse et al., 2010).

Los Derechos de Uso Territorial para la Pesca (TURFs) son herramientas alternativas de manejo espacial pesquero que, en combinación con las AMP, pueden integrar la pesca sostenible y la conservación de la biodiversidad a través de la gestión comunitaria de los recursos (Lester et al., 2017). Los TURFs delimitan espacialmente áreas marinas en las que uno o varios usuarios autorizados, como pescadores individuales, cooperativas o grupos comunitarios, poseen derechos exclusivos para extraer recursos específicos (Christy, 1982). Al restringir el acceso dentro de estas zonas, los TURFs pueden fomentar la corresponsabilidad y una gobernanza local efectiva de los recursos marinos (Aceves-Bueno et al., 2023). Evidencia proveniente de diversos países, incluidos Chile y Japón, sugiere que, cuando se implementan de manera efectiva, los TURFs pueden recuperar poblaciones sobreexplotadas, incrementar la biodiversidad, mejorar la estabilidad de los ecosistemas y fortalecer la cohesión social, logrando resultados ecológicos comparables a los de AMP altamente protegidas (Pérez-Matus et al., 2025, 2017; Gelcich et al., 2012). Por ejemplo, en el centro de Chile, los TURFs con alto cumplimiento han registrado densidades y biomasa del invertebrado *Concholepas concholepas* comparables a las observadas en AMP cercanas sin extracción (Gelcich et al., 2012). Sin embargo, al igual que ocurre con las AMP, la efectividad de los TURFs puede variar ampliamente en función de la gobernanza local y de los contextos socioecológicos (Aceves-Bueno et al., 2023; McCay et al., 2014; Basurto et al., 2013). Por ello, comprender el efecto de los distintos esquemas de TURF sobre la biodiversidad es una prioridad de investigación clave para el manejo pesquero y los esfuerzos globales de conservación.

En México, los recursos bentónicos costeros se manejan mediante TURFs que otorgan a pescadores individuales u organizaciones de pescadores, como las cooperativas, concesiones o permisos de pesca que difieren en duración, regulaciones y condiciones de renovación (DOF, 2024; Aceves-Bueno et al., 2023; McCay, 2017). Estos derechos de propiedad espacial se remontan a las reformas pesqueras de la década de 1930 (McCay et al., 2014). En la costa del Pacífico de la península de Baja California, los TURFs se otorgan para recursos bentónicos como se otorgan para recursos bentónicos como langosta, abulón, erizo, caracol y pepino de mar. Estas especies de alto valor comercial habitan los bosques de kelp gigante (*Macrocystis pyrifera*), un ecosistema altamente productivo y biodiverso que sustenta algunas de las pesquerías de pequeña escala más importantes del país, tanto de invertebrados como de peces (Valdez-Rojas et al., 2022; Ramírez-Valdez et al., 2017; Torres-Moye et al., 2013).

Durante las últimas décadas, México ha perdido más del 50% de sus bosques de kelp debido a eventos extremos de olas de calor marinas y a presiones humanas (Arafeh-Dalmau et al., 2025). Como resultado, muchos de estos ecosistemas han transitado hacia estados dominados por erizos, con impactos significativos sobre la biodiversidad y la economía local (Arafeh-Dalmau et al., 2025; Villaseñor-Derbez et al., 2024; Beas-Luna et al., 2020). Aunque aproximadamente el 40 % de los bosques de kelp en México se encuentran dentro de AMP, estas áreas corresponden principalmente a zonas de amortiguamiento con protección parcial o baja, donde continúan operando pesquerías de pequeña escala y recreativas (Arafeh-Dalmau et al., 2021, 2025). En consecuencia, los TURFs constituyen el marco de manejo predominante a lo largo de aproximadamente 1,000 km de costa. No obstante, aún es limitada la evidencia sobre si estos sistemas gestionados por los usuarios pueden generar beneficios para la biodiversidad. En el sur de la península, se ha documentado la recuperación de los bosques de kelp tras eventos extremos de calentamiento e hipoxia (Arafeh-Dalmau et al., 2025; Micheli et al., 2024; Olguin Jacobson et al., 2025; Micheli et al., 2012). Esta región alberga una de las federaciones cooperativas más antiguas de México, FEDECOOP (fundada en 1940) que posee concesiones exclusivas para la pesca bentónica a lo largo de la costa del Pacífico de Baja California (McCay et al., 2014). Estas cooperativas operan bajo los estándares de sostenibilidad del Marine Stewardship Council (MSC) y mantienen altos niveles de vigilancia y monitoreo biológico, llegando incluso a establecer reservas voluntarias sin extracción, conocidas como “refugios pesqueros” (González-Medina et al., 2025; McCay, 2017; Micheli et al., 2012).

Dado que la mayoría de los bosques de kelp en Baja California se manejan a través de TURFs y no mediante AMP sin extracción, y que estos TURFs difieren ampliamente en su organización, regulaciones y capacidad de cumplimiento, evaluar su efectividad ecológica es esencial. Esto plantea la pregunta de si los esquemas de manejo actuales pueden generar resultados de conservación comparables a los documentados en AMP bien protegidas, particularmente para las especies explotadas. De manera específica,

planteamos la hipótesis de que los TURFs bien manejados sostienen la mayor biomasa de invertebrados y peces de importancia comercial. Para poner a prueba esta hipótesis, evaluamos los efectos ecológicos de distintos contextos de manejo de TURFs a lo largo de la península de Baja California, donde las zonas de pesca se superponen con extensos bosques de *Macrocystis pyrifera*. Con este objetivo, primero mapeamos y caracterizamos los tipos de titulares de TURF asociados a cinco recursos bentónicos clave utilizando datos georreferenciados de la Plataforma Nacional de Transparencia de México. Posteriormente, integramos esta caracterización espacial con monitoreos ecológicos realizados entre 2022 y 2024 en 32 sitios de bosques de kelp, para comparar patrones de biomasa de invertebrados y peces de importancia comercial entre categorías de manejo, tanto a nivel de ensamblaje como a nivel específico de especie. Nuestros resultados muestran que los TURFs bien manejados pueden generar beneficios de conservación para las especies explotadas, lo que representa un hallazgo clave para México y para otras regiones costeras donde los sistemas de derechos espaciales de base comunitaria sustentan los medios de vida locales y la gobernanza pesquera.

1. INTRODUCTION

Fishing has long been one of the most important human activities sustaining coastal communities worldwide. Today, small-scale fisheries (SSF) - which account for more than 90% of the global fishing workforce - provide nearly half of the world's total fish catch (Basurto et al., 2025; FAO et al., 2023). These fisheries are central to food security, employment, and cultural identity across many coastal regions worldwide (Canty & Deichmann, 2022; Short et al., 2021); however, without effective management, overfishing is driving biodiversity loss, eroding the resilience of marine ecosystems to climate impacts, and ultimately threatening the livelihoods of coastal communities (Kumagai et al., 2024; Coll et al., 2010; Coleman & Williams, 2002). To address these challenges, global conservation efforts are aiming to effectively protect and restore 30% of the oceans by 2030 while ensuring sustainable use of resources (Convention of Biological Diversity, 2021).

Marine Protected Areas (MPAs) have been among the most widely adopted and best-documented conservation tools. Well managed and enforced MPAs, such as fully protected no-*take* zones, can increase species diversity, fish biomass, reproductive output, and enhance ecosystem resilience to climate impacts (Olguin Jacobson et al., 2025; Kumagai et al., 2024; Lubchenco & Grorud-Colvert, 2015; Micheli et al., 2012). Despite these benefits, highly protected MPAs currently cover only 3.1% of the world's oceans (MPA Atlas, 2025). MPAs have also been used as fisheries management tools, especially when created as community-based reserves (Smallhorn-West et al., 2020; Villaseñor-Derbez et al., 2019). Nevertheless, when MPAs are not established through participatory approaches, they can create conflict with local communities that depend directly on local resources for their livelihoods, thereby limiting their effectiveness (Jiang et al., 2024; Ferse et al., 2010).

Territorial Use Rights for Fisheries (TURFs) are alternative spatial fishery management tools that combined with MPAs can integrate sustainable fishing and biodiversity conservation through community-based stewardship (Lester et al., 2017). TURFs have spatially defined marine boundaries where one or more authorized users, such as individual fishers, cooperatives, or community groups, hold exclusive rights to harvest specific resources (Christy, 1982). By restricting access within these zones, TURFs can foster shared responsibility and effective local governance of marine resources (Aceves-Bueno et al., 2023). Evidence from several countries, including Chile and Japan, suggests that when effectively implemented, TURFs can rebuild depleted stocks, enhance biodiversity, improved ecosystem stability and strengthen social cohesion, achieving ecological outcomes comparable to highly protected MPAs (Pérez-Matus et al., 2025, 2017; Gelcich et al., 2012). For example, in central Chile well-enforced TURFs have reported densities and biomass of the invertebrate *Concholepas concholepas* comparable to those found in nearby no-take MPAs (Gelcich et al., 2012). Nevertheless, as with MPAs, the effectiveness of TURFs can vary widely depending on local governance and socio-ecological contexts (Aceves-Bueno et al., 2023; McCay et al., 2014; Basurto et al., 2013). Thus, understanding how a variety of TURF schemes can shape biodiversity outcomes remains a research priority to inform fisheries management and global conservation efforts.

In Mexico, benthic coastal resources are managed through TURFs that grant individual fishers or organized groups of fishers (i.e., cooperatives) fishing concessions or permits that differ in duration, regulations and renewal terms (DOF, 2024; Aceves-Bueno et al., 2023; McCay, 2017) These spatial property rights date back to Mexico's 1930s fisheries reforms (McCay et al., 2014). On the Pacific of the Baja California peninsula, TURFs are granted for benthic resources such as spiny lobster, abalone, sea urchins, sea snail and sea cucumber. These commercially important species inhabit the giant kelp (*Macrocystis* *pyrifera*) forests, a highly productive and biodiverse ecosystem that supports some of the country's most important small-scale fisheries for invertebrates and fish (Valdez-Rojas et al., 2022; Ramírez-Valdez et al., 2017; Torres-Moye et al., 2013)

Over the past decades, Mexico has lost over 50% of its kelp forests due to extreme marine heatwaves and human pressures (Arafeh-Dalmau et al., 2025). As a result, many of these ecosystems have now shifted to a transitional sea urchin barren state, with major biodiversity and economic impacts (Arafeh-Dalmau et al., 2025; Villaseñor-Derbez et al., 2024; Beas-Luna et al., 2020) Although ~40% of kelp forests in Mexico are inside MPAs, these areas are inside buffer zones with partial or low protection, where small-scale and recreational fisheries remain active (Arafeh-Dalmau et al., 2025, 2021). Consequently, TURFs constitute the predominant management framework along ~1,000 km of coastline. Whether these user-managed systems can deliver positive biodiversity outcomes remains largely unknown. Evidence from the southern peninsula shows that kelp forests in this region have recovered after extreme warming and hypoxia events (Arafeh-Dalmau et al., 2025; Micheli et al., 2024; Olguin Jacobson et al., 2025; Micheli et al., 2012). This region hosts one of Mexico's oldest cooperative federations, FEDECOOP (founded in 1940) that holds exclusive benthic fishing concessions along the Pacific coast of Baja California (McCay et al., 2014). These cooperatives operate under Marine Stewardship Council (MSC) sustainability standards and maintain high levels of surveillance and biological monitoring, even establishing voluntary no-take reserves ("fishing refuges") (González-Medina et al., 2025; McCay, 2017; Micheli et al., 2012).

Given that most kelp forests in Baja California are managed through TURFs rather than no-take MPAs, and that these TURFs differ widely in their organization, regulations, and enforcement capacity, evaluating their ecological effectiveness is essential and raises the question of whether current management can deliver conservation outcomes comparable to those documented in well-protected MPAs, particularly for harvested species. Specifically, we hypothesized that well-managed TURFs support the highest biomass of commercially important invertebrates and fish. To test this hypothesis, we evaluated the ecological effects of contrasting TURF management conditions along the Baja California Peninsula, where fishing grounds overlap with extensive *Macrocystis pyrifera* forests. Towards this goal, we first mapped and characterized the TURF-holder types associated with five key benthic resources (lobster, abalone, red sea urchin, sea snail, and sea cucumber) using georeferenced data from Mexico's National Transparency Platform. We then integrated this spatial characterization with ecological monitoring surveys conducted from 2022 to 2024 at 32 kelp forest sites to compare biomass patterns of commercially important invertebrate and finfish species across management categories, both at the assemblage level and at the species-specific level. Our results show that well-managed TURFs can provide conservation benefits to harvested species. This is a critical insight for Mexico and for other coastal regions where community-based spatial rights systems underpin local livelihoods and fisheries governance.

2. OBJECTIVES

2.1 GENERAL

To evaluate whether contrasting TURF management conditions deliver positive ecological outcomes for commercially targeted species in kelp forests along the Baja California Peninsula, Mexico.

2.2 SPECIFICS

- To map and characterize TURF-holder types associated with five commercially important benthic resources (spiny lobster, abalone, red sea urchin, sea snail, and sea cucumber) along the Baja California Peninsula, using georeferenced fisheries licensing data.
- To integrate this spatial characterization with long-term ecological monitoring data to classify kelp forest sites according to contrasting TURF management conditions.
- To compare the biomass of commercially targeted invertebrates and reef-associated fishes across TURF management conditions at both the assemblage and species-specific levels.

3. METHODS

3.1 STUDY REGION

This study was conducted along the Pacific coast of the Baja California Peninsula, ranging from the Coronado Islands (~32.5°N) to Bahía Asunción (~27.1°N) (Figure 1). Marine ecosystems in this region are highly influenced by the California Current System, characterized by the southward-flowing California Current (Durazo et al., 2010), which delivers cold, nutrient-rich waters and fuels seasonal upwelling and high primary productivity (Checkley & Barth, 2009). Kelp forests are iconic ecosystems along this coastline. They are mainly formed by the giant kelp (*Macrocystis pyrifera)*, which typically extends from 5 to ~20 m depth over rocky reefs and are often mixed with other forest-forming kelps, such as Southern Sea palm (*Eisenia arborea*), and Woody kelp (*Pterygophora californica*) (Arafeh-Dalmau et al., 2021; Beas-Luna et al., 2020; Cavanaugh et al., 2019; Foster, 1975), among others. Notably, Bahía Asunción marks the contemporary southern distributional limit of *M. pyrifera* in the northeastern Pacific (Arafeh-Dalmau et al., 2021; Cavanaugh et al., 2019)

These highly productive ecosystems support important small-scale coastal fisheries which are managed under a mosaic of benthic TURFs. In the northern section (Coronado Islands–El Rosario), TURFs are characterized by diffuse access, with multiple users operating and competing for resources and common reports of illegal fishing (Ponce-Díaz et al., 2013). In contrast, in parts of the northern sites and all of the southern sites of our study area (El Rosario–Bahía Asunción), TURFs are exclusively managed by cooperatives with well-defined spatial boundaries, where communities have direct control over local harvest and equitable profit-sharing among members (McCay et al., 2014). While large MPAs (e.g., Biosphere reserves) exist in Baja California, they mostly have low-levels of protection due to the absence of management plans or weak regulations of human activities.

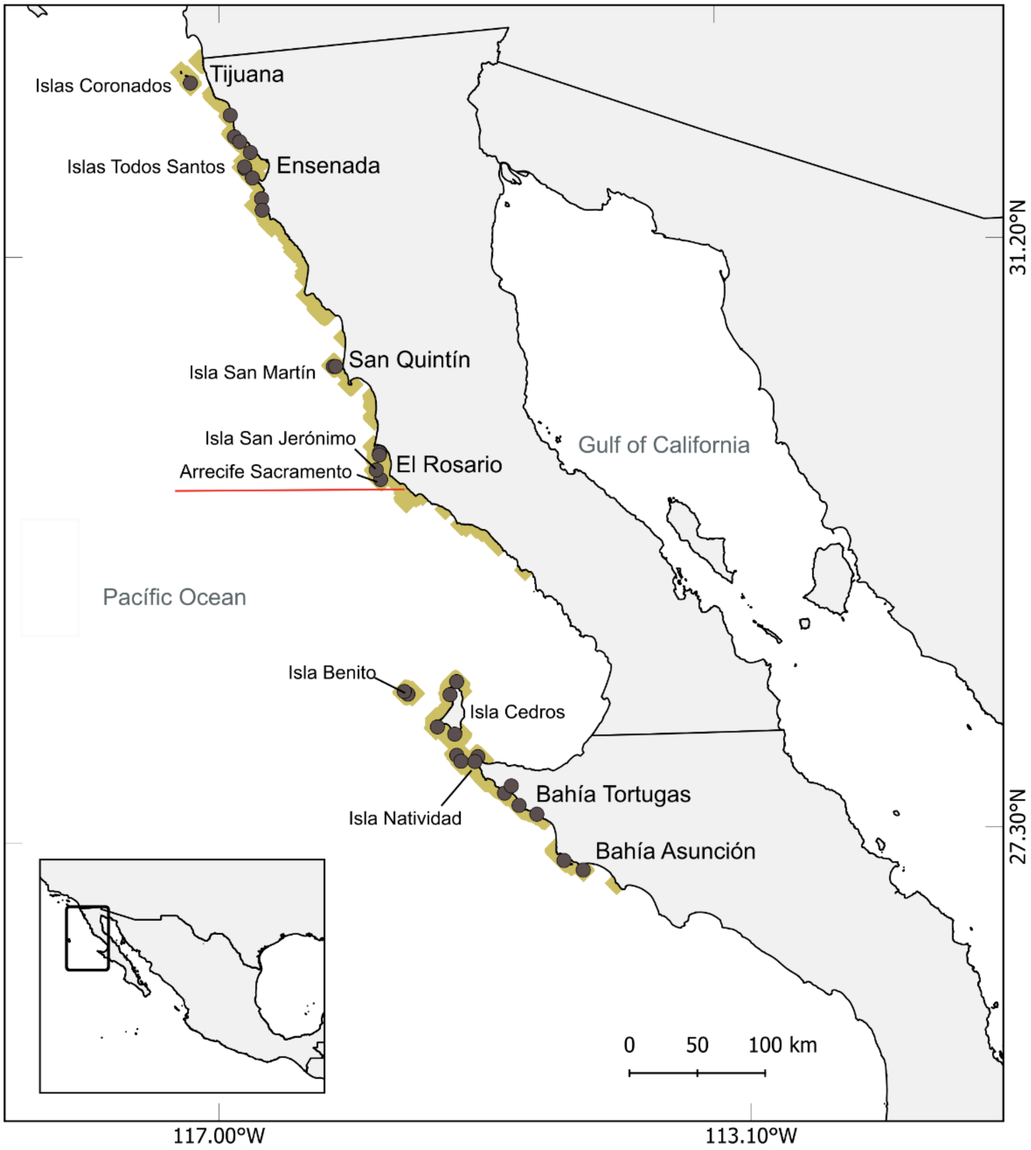

Figure 1. Kelp forests distribution and monitoring sites along the Baja California Peninsula. Study area along the Pacific coast of the Baja California Peninsula showing the distribution of giant kelp (*M. pyrifera*) forests (yellow polygons) and kelp forest monitoring sites (black dots) surveyed for at least two years between 2022 and 2024 (n = 32 of 42 sites). The red horizontal line at 29.73° N marks the biogeographic boundary separating northern and southern Baja California subregions. Kelp polygons (Arafeh-Dalmau et al., 2021) borders were slightly enlarged for improved visualization over sampling sites.

3.2 MANAGEMENT CATEGORIES ALONG THE PENINSULA

Using publicly available information from Mexico's National Transparency Platform (https://www.plataformadetransparencia.org.mx/datos-abiertos), we obtained the boundaries of five benthic TURFs linked to commercially valuable small-scale fisheries resources: spiny lobster (*Panulirus interruptus*), abalone (*Haliotis* spp.), red sea urchin (*Mesocentrotus franciscanus*), sea snail (*Megastraea* spp.*)* and sea cucumber (*Apostichopus parvimensis*), across our study area (Figure 2).

The database included the geographic coordinates of authorized fishing polygons for each TURF, extraction localities, license type (concession or permit holders), licenses duration, and the users associated with each license. Because Concessions and Permits last ten and two years, respectively, we only considered licenses granted between 2010 and 2022, to assess the recent fisheries management history.

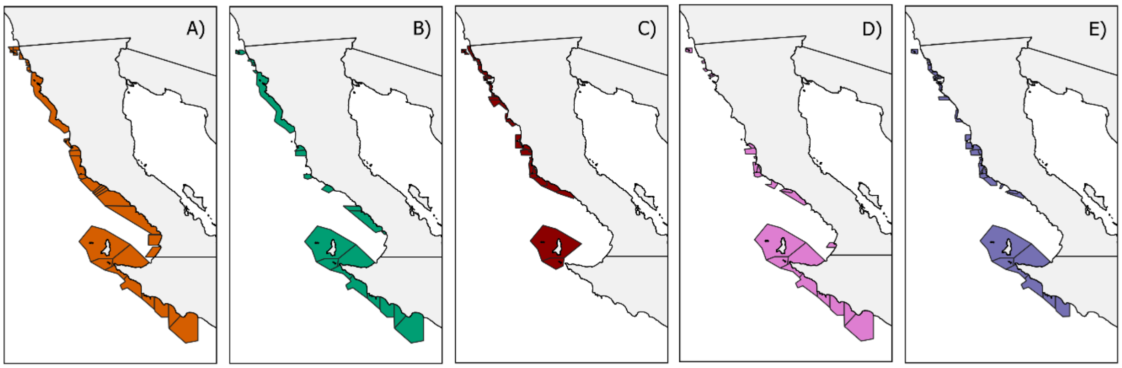

Figure 2. Mosaic of TURF-based benthic fisheries along the Baja California Peninsula. The five maps illustrate the spatial distribution of TURFs associated with small-scale benthic fisheries included in this study. Each panel represents a distinct fishery resource: (A) spiny lobster (*Panulirus interruptus*), (B) abalone (*Haliotis* spp.), (C) red sea urchin (*Mesocentrotus franciscanus*), (D) sea snail (*Megastraea* spp.), and (E) sea cucumber (*Apostichopus parvimensis*). Colored polygons correspond to licensed TURF areas obtained from Mexico's National Transparency Platform (2010–2022) and are enlarged for clarity.

3.3 ECOLOGICAL MONITORING

We conducted ecological monitoring annually in August between 2022 and 2024 across 41 sites along the Baja California Peninsula, covering ~800 km of continental and insular coastline (Figure 1). Surveys were carried out collaboratively by Universidad Autónoma de Baja California (UABC), MasKelp Foundation, Stanford University, Comunidad y Biodiversidad A.C. (COBI), and FEDECOOP (federation of local fishing cooperatives from Baja California), following MasKelp monitoring protocols (Garcia-Pantoja et al., *in prep*) that use similar methodologies to PISCO and Reef Check (Freiwald et al., 2021; Malone et al., 2022). Site selection was based on UABC monitoring program that started in 2011, as well as published maps of historical *M. pyrifera* forest presence in the region, derived from a 35-year satellite time series (Arafeh-Dalmau et al., 2021). The protocol surveys forests over 1 km in length, with two sub-sites selected within each forest, located near the center and separated by approximately 500 m. At each sub-site, three 30 × 2 m transects were established, surveyed on scuba, and placed parallel to the coastline at depths ranging from 8 to 20 m (mean 12.70 ± 3.45 m), oriented towards the opposite sub-site, for a total of six transects per site. Within each transect, we quantified the abundance of benthic macroinvertebrates (> 2.5 cm) and both the abundance and size of fishes, recording fish total lengths in 5-cm intervals. We included in analyses only sites with at least two years of monitoring, resulting in a final dataset of 32 sites for invertebrates and 31 sites for fish.

3.4 INVERTEBRATES AND FISH BIOMASS

We estimated the biomass of invertebrates and reef-associated fish at both group and species-specific level, focusing on taxa of commercial interest directly affected by fishing activities and national management plans. From our original list (55 invertebrate and 76 fish species), we retained the five invertebrate species harvested under Concessions or Permits within benthic TURFs (Figure 2). For fish, we retained only species of commercial importance listed in the Mexican National Fisheries Inventory (DOF, 2023) with total lengths ≥ 25 cm, representing medium- to large-bodied individuals that serve as reliable indicators of well-managed areas (Graham, 2004). This selection resulted in a final set of 28 fish species (Table S1).

We derived biomass of invertebrates from survey-based data abundance combined with species-specific mean biomass reported in the literature (Table S2; Olguin Jacobson et al., 2025; Woodson et al., 2019). Resulting values were expressed in kg/m² and standardized to the sampling area of each transect (60 m²). Fish biomass was estimated using species-specific length–weight conversion parameters (a, b) obtained from FishBase (https://www.fishbase.se/search.php). Individual weight (W, in kg) was calculated using the equation $W = a \times L^b$, where L is the total length (cm) recorded during diver surveys. Biomass per transect was then calculated as $B = W \times A$, where A is the species' abundance and standardized to kg/m² for the 60 m² sampling area. We calculated biomass for each species separately and combined at the invertebrate and fish group levels.

To minimize potential bias resulting from species thermal affinities and biogeographic distribution, we estimated their latitudinal distribution centers (from FishBase) to identify two representative species that lie within the central portion of our study area (~29.5°N) (Table S3) and that are important commercial species. This resulted in the selection of *P. interruptus* and *Haliotis spp*. for invertebrates, and California sheephead (*Bodianus pulcher)* and Kelp bass (*Paralabrax clathratus)* for fish. Although the distribution centroid of kelp bass falls near 35°N, the species becomes much less common north of Point Conception (~34.5°N) (Kells et al., 2016; Humann & DeLoach, 1996). Therefore, its effective centroid of distribution along the Pacific coast is likely closer to ~29°N.

3.5 DATA ANALYSIS

3.5.1 SPATIAL OVERLAP AND SITE CATEGORIZATION

We georeferenced the five TURFs using QGIS 3.36.3 and overlaid with the ecological monitoring sites. Around each site, we applied a 100 m buffer radius to match the spatial extent of the transect-based surveys (three 30 m transects, ~90 m total). Within this buffer, we quantified the number of license holders and the type of license associated with each resource. Based on these attributes, and in consultation with key actors, sites were classified into three management categories: (1) single concession holder (Concession), (2) single permit holder (Permit), and (3) mixed concession and permit holders (Mixed) (Table S4). This classification reflects in tenure and organization: Concessions are long-term licenses (10 years) usually held by organized cooperatives with well-defined organizational frameworks and regular surveillance, sometimes including-community-based non-take MPAs. Permits are short-term licenses (2 years) with more limited organizational capacity. Mixed sites include both types of licenses, where multiple users operate in the same area, which can create conflict.

To better contextualize this classification, we conducted an expert knowledge survey with key actors, including researchers from UABC, staff from the Mexican Institute of Fisheries and Aquaculture Research (IMIPAS), and independent consultants in ecology and fisheries. The survey assessed site-level attributes related to monitoring efforts (frequency, type of monitoring, and the actors involved), as well as patrolling/surveillance activities to control illegal fishing (absent or continuous/24-7). Key actors also scored the degree of local engagement at each site, distinguishing whether fishing activities were primarily conducted by local community members or by temporary employees.

3.5.2 MULTIVARIATE ANALYSIS FOR BIOGEOGRAPHY PATTERNS

To evaluate potential latitudinal effects associated with the location of our sites, we conducted multivariate community structure analyses. First, we performed a non-metric multidimensional scaling (nMDS) based on Bray–Curtis dissimilarities of Hellinger-transformed density data (individuals m^{-2}) to examine spatial variation in invertebrate and fish community structure across the Baja California Peninsula. The dataset included all taxa recorded across monitoring sites ($n = 55$ invertebrates; $n = 76$ fish). Species densities were averaged by site and year, and only sites surveyed in at least two years were retained ($n = 32$ invertebrate sites; $n = 31$ fish sites). The ordination was constructed with two dimensions ($k = 2$) and 9,999 permutations to ensure the stability of the solution. The final configuration showed a low stress value (Figures S1 and S2), indicating good fit between ordination distances and observed dissimilarities.

We then conducted a permutational multivariate analyses of variance (PERMANOVA; *adonis2* function, *vegan* package) using subregion (north vs. south, see below) as a categorical predictor to assess spatial effects on community structure. Because PERMANOVA does not accommodate continuous predictors such as latitude, we classified sites into two subregions based on the spatial clustering observed in the nMDS ordination (see Results, Figure 4-5). Accordingly, sites located north of 29.73° N latitude were classified as northern, and those south of this latitude (≤ 29.73° N) as southern. We used *betadisper* to verify homogeneity of multivariate dispersion among groups.

To identify the species contributing to the significant differences detected by PERMANOVA, we applied a Dufrêne–Legendre Indicator Species Analysis (Dufrene & Legendre, 1997) using the generalized IndVal.g statistic. The analysis was conducted with the *multipatt* function in the *indicspecies* package, following the methodological updates of De Cáceres & Legendre, (2009). This method quantifies both the specificity and fidelity of each species to a given subregion. Statistical significance was assessed with 999 permutations, and species with $p \leq 0.05$ were considered significant indicators.

All analyses were conducted in R version 4.3.3 (R Core Team, 2024) using the vegan package (Oksanen et al., 2012) within RStudio (Posit Software, PBC). Because subregion comprised only two levels, no post-hoc pairwise comparisons were required.

3.5.3 UNIVARIATE ANALYSIS

We used generalized linear mixed models (GLMMs) with a Tweedie distribution and a log-link function to model total biomass of fish and invertebrate assemblages, as well as species-specific taxa, as a function of management regime (three levels: Concession, Permit, Mixed), year (three levels: 2022–2024), and their interaction. *Site* was included as a random effect to account for repeated measures and site-level variation. The choice of error distribution was guided by data structure, zero-inflation patterns, and overall model performance. Only sites monitored for at least two years were retained in the analysis (n = 32 invertebrate sites; n = 31 fish sites). Subsites (north and south) within each location were treated as part of the same site, with their variation captured by the random effect of *Site* in the model.

We fit separate GLMMs for the overall fish and invertebrate assemblages, as well as for each species-specific taxon. For the invertebrate and fish assemblages, we retained the full models including the interaction term, as it provided the best fit and allowed testing for temporal changes across management regimes. Species-specific models followed the same structure but were simplified by removing interactions when not significant ($p > 0.05$) and if their removal did not increase the Akaike's Information Criterion (AIC). We used the full models for most taxa (spiny lobster, sea snail, sea cucumber, California sheephead and kelp bass), as this model specification effectively captured continuous, right-skewed data with moderate zero inflation.

For abalone, we dropped the interaction between management and year because the full model failed to converge, likely due to the near absence of abalone in some management categories (Permit and Mixed); the additive structure provided stable estimates and the lowest AIC. For red sea urchin, we used a zero-inflated Tweedie GLMM because the biomass data were highly skewed and contained many zeros. Incorporating zero-inflation markedly improved model diagnostics, and the model allowing zero-inflation to vary by management and year provided the most reliable fit, even if not the lowest AIC.

We estimated marginal means (± SE) for each category and year using the *emmeans* package and back-transformed to the response scale for visualization. All analyses were conducted in R version 4.3.3 (R Core Team, 2024) using the packages *glmmTMB* (Brooks et al., 2017) for model fitting, *emmeans* for post hoc comparisons, and *car* for Wald Type III ANOVA test, and "DHARMa" to assess the model residual diagnostics (Hartig, 2024). DHARMa diagnostic plots are provided in the Supplementary Material (Figures S3–S11).

4. RESULTS

4.1 CHARACTERIZING MANAGEMENT REGIMES

Of our 32 monitoring sites, 19 are in fishing Concessions, 5 in Permit areas and 8 Mixed (Figure 3). These categories exhibited a distinct latitudinal gradient along the Baja California Peninsula. Permit sites were restricted to the northern region, particularly around Tijuana and northern Ensenada. Mixed sites were also concentrated in the north, extending southward around the Ensenada area and reaching one central site, Isla San Martín. Concession sites dominated the southern portion of the peninsula, from Cedros Island to Bahía Asunción, within and around the Vizcaino Biosphere Reserve and in parts of the central region in El Rosario, except in Arrecife Sacramento that has a permit.

Based on the survey knowledge information compiled for each site, three contrasting management conditions emerged across the peninsula. Sites under Permits (P) and Mixed regimes (M) consistently showed absent or inconsistent surveillance, irregular biological monitoring, conducted solely by government institutions, and operated mainly by temporary, non-local users. In contrast, concession sites (C) exhibited continuous 24/7 surveillance, annual biological monitoring conducted by the cooperative, and managed by locally rooted members with long-term affiliation to the community. These characteristics reflect clear differences in enforcement capacity, monitoring effort, and sense of belonging among TURF-holder types (Table S5).

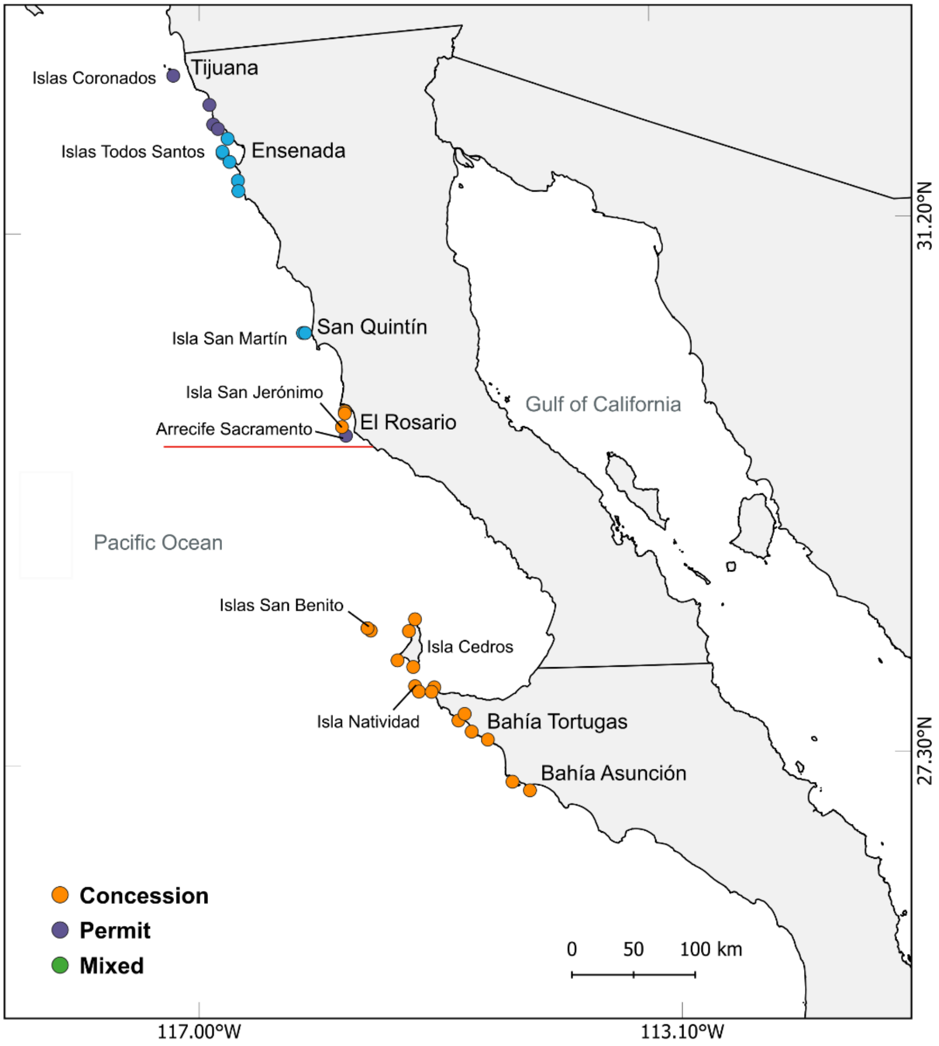

Figure 3. Spatial distribution of fisheries management along the Baja California Peninsula. Each point represents one of the 32 ecological monitoring sites, classified as concession (orange), permit (purple), or mixed (blue). The red horizontal line at 29.73° N marks the biogeographic boundary separating northern and southern Baja California subregions.

4.2 COMMUNITY STRUCTURE

Multivariate analyses of invertebrate and fish assemblages across the Baja California Peninsula revealed strong and significant spatial structuring between northern and southern subregions (PERMANOVA; Supplementary Tables S8 and S9). nMDS ordinations showed a clear latitudinal pattern, with higher-latitude sites (> 27.73° N) clustering on the left side of the ordination space and lower-latitude sites (< 27.73° N) spreading to the right (Figures 4 and 5). This pattern also revealed a transitional zone near the latitudinal breakpoint, composed of four intermediate sites: Isla San Jerónimo, El Rosario Picacho, El Rosario Lázaro, and Arrecife Sacramento, of which the first three are concession sites, while Arrecife Sacramento operates under a permit regime. The pattern was particularly pronounced in invertebrate assemblages, which formed two well-defined clusters (Figure 4). Fish assemblages showed a similar structure but shifted more gradually with latitude, resulting in a smoother compositional transition (Figure 5). Tests for homogeneity of dispersion further indicated significantly greater within-group variability among southern sites, both for invertebrates (BETADISPER: F = 16.28, p = 0.001) and fishes (F = 16.24, p = 0.002), supporting the higher compositional heterogeneity of assemblages in the southern subregion.

The Dufrêne–Legendre Indicator Species Analysis revealed strong taxonomic differentiation between northern and southern subregions for both invertebrates and fishes. Among invertebrates, 33 species were identified as significant indicators (Table S6), with 19 characterizing the northern subregion, including *Patiria miniata*, *Mesocentrotus franciscanus*, *Strongylocentrotus purpuratus*, and *Pisaster giganteus*, and 14 associated with the southern subregion, such as *Eucidaris thouarsii*, *Haliotis spp.*, *Muricea californica*, and *Panulirus interruptus*. Fish showed a similar pattern, with 30 significant indicator species (Table S7). Northern sites were dominated by 18 species, including *Oxylebius pictus*, *Oxyjulis californica*, *Sebastes atrovirens*, *Chromis* *punctipinnis*, and *Rhinogobiops nicholsi*. The southern subregion exhibited 12 indicator species, notably *Halichoeres semicinctus*, *Paralabrax clathratus*, *Girella nigricans*, *Medialuna californiensis*, and *Anisotremus davidsonii.*

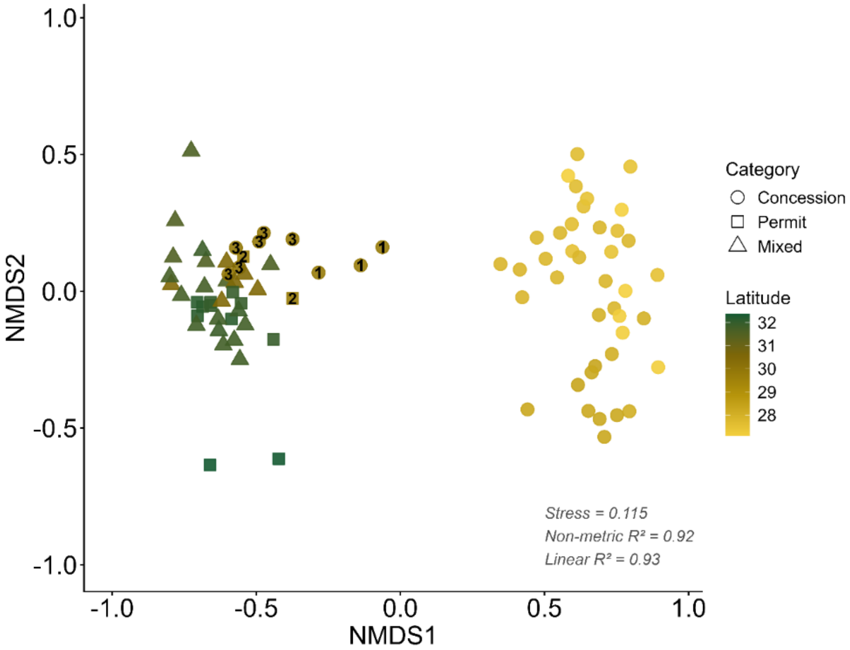

Figure 4. Non-metric multidimensional scaling (nMDS) ordination based on Bray–Curtis dissimilarities of Hellinger-transformed data for benthic invertebrate assemblages across 32 monitoring sites that had at least two years of data. Each point represents a site assemblage for a given year (2022, 2023, or 2024). Symbols indicate fisheries management categories (Concession, Permit, Mixed), while colors represent the mean latitude of each site. Numbers identify key central sites: (1) Isla San Jerónimo, 2) Arrecife Sacramento, and (3) El Rosario (Lázaro and Picacho).

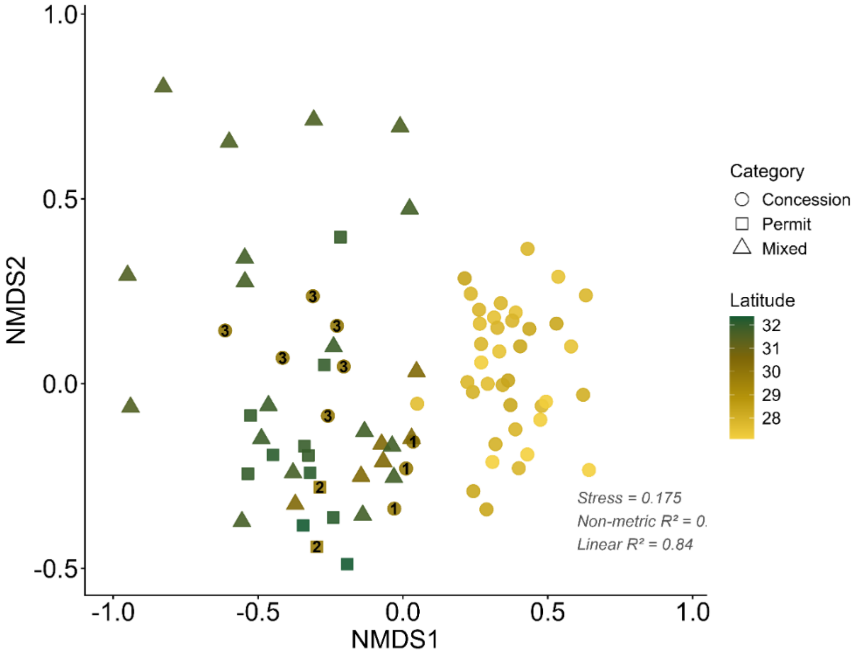

Figure 5. Non-metric multidimensional scaling (nMDS) ordination based on Bray–Curtis dissimilarities of Hellinger-transformed data for reef fish assemblages across 32 monitoring sites that had at least two years of data. Each point represents a site assemblage for a given year (2022, 2023, or 2024). Symbols indicate fisheries management categories (Concession, Permit, Mixed), while colors represent the mean latitude of each site. Numbers identify key central sites: (1) Isla San Jerónimo, (2) Arrecife Sacramento, and (3) El Rosario (Lázaro and Picacho).

4.3 BIOMASS PATTERNS ACROSS MANAGEMENT REGIMES

4.3.1 INVERTEBRATE BIOMASS PATTERNS

Across management categories, total invertebrate biomass exhibited contrasting patterns at the harvested invertebrate species group and species levels (Figure 6). The biomass of invertebrate species group did not differ among management categories for 2022 (Figure 6a, Table 1). However, in 2023 and 2024 Concessions exhibited significantly lower biomass than Permit and Mixed sites (except with permit holders in 2023), with concession having 2–2.3 times lower biomass than Permit and Mixed sites. Therefore, these results suggest a mixed pattern among years, but a general lower total invertebrate biomass in fishing Concessions in 2023 and 2024. This pattern was driven primarily by red sea urchins, which accounted for more than 50% of total invertebrate biomass in Permit and Mixed sites. Their biomass in these site categories was significantly higher than in Concessions, being 8 times higher. This is likely due to red sea urchins having the northernmost latitudinal centroid among the harvested species (Figure 6d; Table S3), making them more abundant in the regions where Permit and Mixed sites dominate.

When looking at the species whose centroid of distribution lies near the center of the study region (Table S3) we found strong and consistent management effects. The biomass of spiny lobster and abalone was significantly higher inside concession than in the other two management categories (Figure 6b, d, Table 1), being 8 to 90 times and over 150 times higher, respectively. In both cases, Permit and Mixed sites consistently showed near-zero biomass, and no significant differences were detected between them. For the remaining species, biomass patterns followed a different direction (Figures 6c, e, f). Sea snail and sea cucumber were not significantly influenced by management categories (Figure 6e, Table 1), and biomass for both species remained within similar values across categories and years.

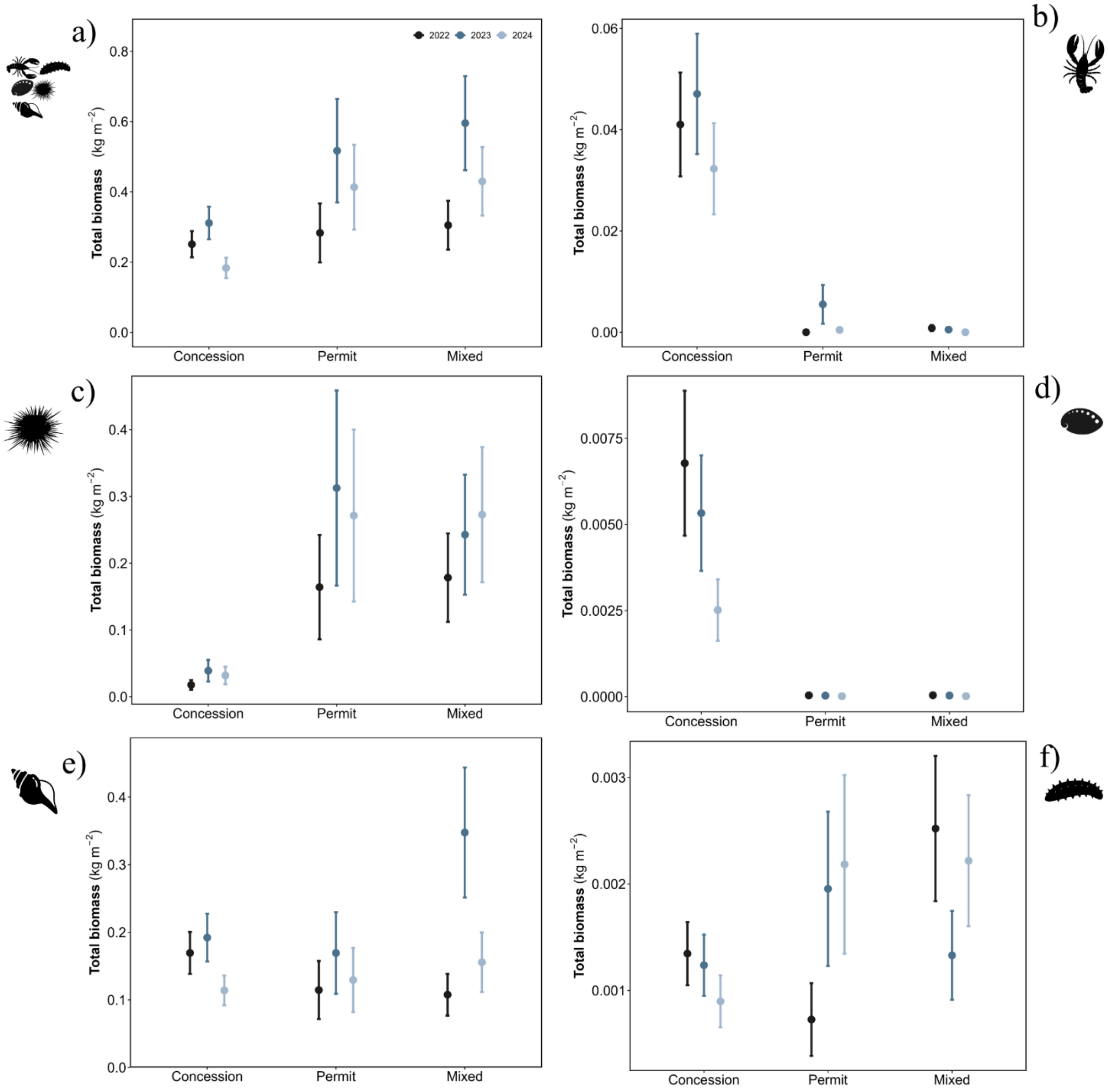

Figure 6. Temporal variation in total biomass (kg m⁻²) of benthic invertebrates across fisheries management categories (Concession, Permit, Mixed) during 2022–2024. Panels show (a) total biomass of invertebrate species harvested within benthic TURFs, (b) California spiny lobster, (c) red sea urchin, (d) abalone, (e) sea snail, and (f) sea cucumber. Symbols represent mean annual biomass ± SE (2022 = black, 2023 = dark blue, 2024 = light blue).

4.3.2 FISH BIOMASS PATTERNS

In contrast to the variable responses observed in invertebrates, fish biomass exhibited strong and persistent differences among Concessions and the other management categories across all years (Figures 7a-c, Table 2). Total fish biomass (28 species) was consistently higher in concession sites (Figure 7a), followed by Permit and Mixed sites, with effect ratios ranging from 2–14-fold depending on the year. Differences were present but less marked in 2022, when only the contrast between Concession and Mixed sites was significant, while 2023 and 2024 Concessions had significantly higher biomass than the other categories. The two indicator species, California sheepshead and kelp bass, closely mirrored these trends (Figures 7b, c, Table 2), having 10 times and 12 times higher biomass, respectively, in Concessions than the other two categories. Across all years and species, there were no differences in the biomass of the total fish biomass or the two indicator species in the Permit and Mixed sites.

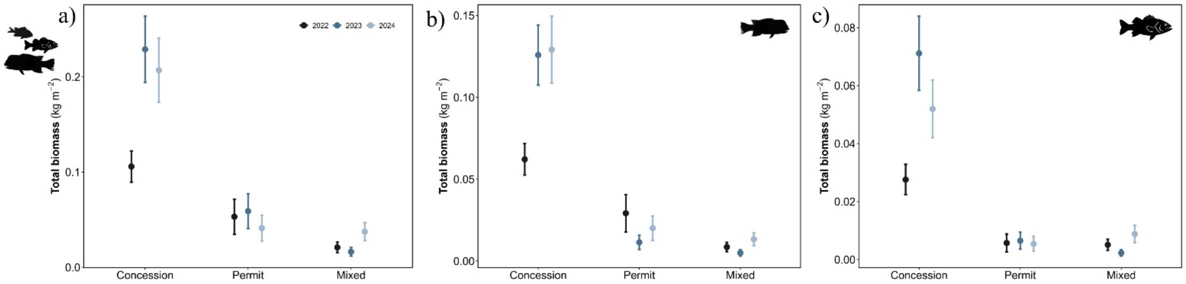

Figure 7. Temporal variation in total biomass (kg m⁻²) of reef fish across fisheries management categories (Concession, Permit, Mixed) from 2022 to 2024. Panels show (a) total biomass of commercial reef fish species, (b) California sheephead, and (c) kelp bass. Symbols represent mean annual biomass ± SE (2022 = black, 2023 = dark blue, 2024 = light blue).

Table I. Pairwise tests for significant differences among years within each management category for harvested invertebrates (n = 5 taxa) and the species-specific models for lobster, sea snail, and sea cucumber. For abalone and red sea urchin, where no interaction was detected, values reflect overall year effects from the simplified GLMMs. Asterisks (*) mark comparisons where the denominator was zero (x/0), producing non-interpretable ratios. In these cases, the *p*-value is returned as 1.000 by the software, but this value has no biological meaning.

		Invertebrates		**Lobster**		**Sea snail**		**Sea cucumber**		**Abalone**		**Red urchin**	
Year	**Comparison**	**Ratio**	***p* value**	**Ratio**	***p* value**	**Ratio**	***p* value**	**Ratio**	***p* value**	**Ratio**	***p* value**	**Ratio**	***p* value**
2022	C / P	0.89	0.9300	*	1.0000	1.48	0.6165	1.85	0.4979	172.32	**<0.0001**	0.12	**0.0010**
2022	C / PC	0.82	0.7529	50.32	**<0.0001**	1.57	0.3759	0.53	0.1759	155.73	**<0.0001**	0.12	**0.0002**
2022	P / PC	0.93	0.9782	0.00	1.0000	1.06	0.9906	0.29	0.0505	0.90	0.9974	1.06	0.9951
2023	C / P	0.60	0.2559	8.55	**0.0087**	1.13	0.9469	0.63	0.5690	172.32	**<0.0001**	0.12	**0.0010**
2023	C / PC	0.52	**0.0431**	90.67	**<0.0001**	0.55	0.1749	0.93	0.9817	155.73	**<0.0001**	0.12	**0.0002**
2023	P / PC	0.87	0.9199	10.60	0.0661	0.49	0.2488	1.47	0.6966	0.90	0.9974	1.06	0.9951
2024	C / P	0.44	**0.0381**	70.49	**0.0005**	0.88	0.9501	0.41	0.1525	172.32	**<0.0001**	0.12	**0.0010**
2024	C / PC	0.43	**0.0057**	*	1.0000	0.73	0.6339	0.40	0.0530	155.73	**<0.0001**	0.12	**0.0002**
2024	P / PC	0.96	0.9940	*	1.0000	0.83	0.9159	0.98	0.9994	0.90	0.9974	1.06	0.9951

Note. Bold *p*-values denote statistically significant differences.

Table II. Pairwise tests significant differences among years within each management category for the fish assemblage (n = 28 taxa) and the species-specific models for California sheephead and kelp bass.

		Fish		**California sheephead**		**kelp bass**	
Year	**Comparison**	**Ratio**	***p* value**	**Ratio**	***p* value**	**Ratio**	***p* value**
2022	C / P	1.99	0.1626	2.13	0.1704	4.83	**0.0162**
2022	C / PC	5.06	**<0.0001**	7.22	**<0.0001**	5.45	**0.0002**
2022	P / PC	2.54	0.0799	3.40	0.0418	1.13	0.9817
2023	C / P	3.88	**0.0003**	10.97	**<0.0001**	10.94	**<0.0001**
2023	C / PC	13.97	**<0.0001**	25.15	**<0.0001**	31.11	**<0.0001**
2023	P / PC	3.60	0.0061	2.29	0.2797	2.84	0.2529
2024	C / P	5.03	**<0.0001**	6.43	**<0.0001**	9.59	**<0.0001**
2024	C / PC	5.53	**<0.0001**	9.65	**<0.0001**	5.90	**<0.0001**
2024	P / PC	1.10	0.9715	1.50	0.6624	0.62	0.6847

Note. Bold *p*-values denote statistically significant differences.

5. DISCUSSION

We provide empirical evidence of the conservation benefits that well managed and highly enforced TURFs can deliver to coastal ecosystems and small-scale fisheries. TURFs are increasingly recognized as spatial management tools capable of sustaining local livelihoods and biodiversity (Gelcich et al., 2010, 2012). Yet, as with MPAs, their ecological performance varies widely with governance and management effectiveness (Brown et al., 2023; Grorud-Colvert et al., 2021; Gill et al., 2017; Edgar et al., 2014). Drawing from three years of surveys conducted at 32 kelp forest sites along 800km of the Baja California Peninsula, we found that Concession sites (well-managed TURFs) characterized by long-term tenure and exclusive access rights consistently supported higher biomass of commercially important species than Permit and Mixed TURFs operating under short-term or multiple user arrangements. Biomass of high-value invertebrates such as abalone and spiny lobster was 8-150 times higher and biomass of common fish species such as California sheephead and kelp bass were 2-31 times higher compared to poorly managed and enforced TURFs. These results align with global evidence that highly enforced TURFs can achieve biomass levels comparable to strongly protected MPAs (Smith et al., 2025; Grorud-Colvert et al., 2021; Edgar et al., 2014; Lester et al., 2009), reinforcing the central role of governance capacity in determining ecological performance in spatial fisheries systems (Franco-Meléndez et al., 2021; Nguyen Thi Quynh et al., 2017; Gelcich et al., 2012). As nations work toward the 30% marine conservation target (Convention of Biological Diversity, 2021), our findings provide globally relevant evidence that effectively managed and well enforced TURFs may qualify as Other Effective Area-based Conservation Measures (OECMs) and meaningfully contribute to this goal.

However, understanding why some TURFs perform better than others require examining the governance structures and processes that shape ecological outcomes. Across TURF categories, our qualitative survey indicate that concession sites exhibited the strongest governance attributes, including continuous on-site surveillance (24/7), biological monitoring conducted by the cooperative, and membership composed of long-standing and locally rooted fishers, as also reported by previous studies (González-Roca et al., 2025; Aceves-Bueno et al., 2023; McCay, 2017; Aburto-Oropeza et al., 2016; McCay et al., 2014). Some concession sites even implement community-designed fishing refugia or local no-take areas (Olguin Jacobson et al., 2025; Villaseñor-Derbez et al., 2025; Perera-Valderrama et al., 2023; Villaseñor-Derbez et al., 2019). These governance and institutional features likely explain the ecological performance observed in concession-managed sites and are consistent with well-known principles of local governance and compliance in common-pool resource systems (Ostrom, 1990).

Similar patterns have been documented for MPAs and OECMs globally, where ecological outcomes depend not on the formal label of protection but on its effective enforcement (Grorud-Colvert et al., 2021; Gill et al., 2017; Edgar et al., 2014). Just as well-enforced no-take MPAs outperform “paper parks”, well-enforced TURFs may sustain better ecological outcomes than TURFs with unstable fishing rights, lack of biological monitoring, and low community cohesion. This was reflected in our results: in the northern region, where four poorly enforced MPAs overlap with Permit and Mixed

TURFs, abalone and lobsters were virtually absent, and fish biomass remained low. Moreover, well-managed TURFs coincide with higher biomass than other sites, with a similar magnitude - typically 2-3 times higher - as no-take MPAs compared to fished areas (Edgar et al., 2014; Lester et al., 2009). Taken together, these results indicate that both conservation tools share mechanisms that can drive their conservation benefits, and that well-managed TURFs represent a tool with great potential to contribute to national and global conservation targets. In fact, in Baja California, our results suggest that conservation benefits are delivered primarily by well-managed TURFs rather than by MPAs, further reinforcing that effectively achieving 30x30 targets in some regions worldwide may require other approaches, in addition to MPAs.

Interpreting management outcomes from regional analyses requires explicit consideration of biogeographic context, as natural patterns of species distribution can mask, confound or mimic the effects of management (Blanchette et al., 2008; Roberts et al., 2003). For this reason, a key objective of our study was to assess whether latitudinal gradients could confound observed management effects. Our multivariate analyses detected a clear biogeographic transition in invertebrates and fish community composition around 29–30° N, consistent with environmental gradients in the region (Fenberg et al., 2014; Blanchette et al., 2008). This transition coincides with the spatial distribution of TURF management categories: most Permit and Mixed TURFs are concentrated north of this latitude, whereas well-managed TURFs predominate in the south (except for four sites around the transition zone). To distinguish biogeographic from management-driven responses, we examined species distributional centroids. The higher biomass of harvested invertebrates observed in Permit and Mixed TURFs was largely driven by red sea urchin, which accounted for >50% of the total invertebrate biomass and has the northernmost distributional centroid among the five harvested species (~45° N). Given its strong latitudinal distribution, this pattern likely reflects biogeographic processes rather than the effects of local fisheries management. In contrast, species whose centroids of distribution are near the middle of the peninsula (~29.5° N) did not follow a latitudinal gradient in biomass; instead, they exhibited higher biomass in well-managed concession TURFs, suggesting their biomass patterns are driven by a fisheries management rather than biogeography.

Notably, this study provides the first regional-scale characterization of biogeographic patterns in fish and macro-invertebrate communities associated with giant kelp forests along the Baja California peninsula, establishing a baseline for future evaluations of the drivers of community structure. While previous work has emphasized the role of latitudinal environmental gradients and the impacts of extreme warming events in structuring kelp forest communities along the California Current (Arafeh-Dalmau et al., 2025; Michaud et al., 2022; Beas-Luna et al., 2020; Arafeh-Dalmau et al., 2019), our results suggest that fisheries management can also play an important role in shaping community composition across this biogeographic context.

The mechanisms underlying kelp forest resilience are tightly linked to top-down control by herbivore predators, whose abundance can regulate grazing pressure and prevent shifts to urchin-dominated states (Arafeh-Dalmau et al., 2025; Eisaguirre et al., 2020). Recent work focused in MPAs has shown that differences in management enforcement strongly influence herbivore predator biomass and kelp coverage (Arafeh-Dalmau et al., 2025).

Consistent with this pattern, our results show that key urchin predators (lobster and sheephead) were largely absent or occurred at very low biomass in poorly managed TURFs compared to well-managed ones. Although we did not quantify kelp cover or purple urchin biomass, these patterns suggest that well-managed TURFs can influence kelp forest resilience by shaping predator populations, thereby modulating trophic interactions that determine whether kelp forests persist or shift toward alternative stable states (Arafeh-Dalmau et al., 2025).

Longer time series would allow a more robust assessment of interannual variability and ecological responds to climatic events. Moreover, surveys conducted once/year cannot capture seasonal variability. Likewise, incorporating broader fisher and resource managers interviews (e.g., MPAs, fishing refuges) and quantitative socioeconomic indicators would complement our expert-based survey and strengthen inference on TURFs performance. Although our analyses captured a clear latitudinal transition in community composition, a more detailed characterization of environmental drivers, such as temperature regimes, would further increase understanding on how biogeographic structure interacts with management. Despite these limitations, our study provides a robust, spatially extensive assessment of the ecological outcomes of TURF for targeted invertebrate and fish species based on three years of underwater surveys at 32 sites across ~800 km of coastline. Although some interannual variability was observed, particularly for fish biomass, patterns were highly consistent across years and management categories, supporting the robustness of our conclusions.

Our work provides evidence that highly enforced TURFs can deliver substantial benefits to coastal ecosystems. Our hypothesis that well-managed TURFs would support higher biomass of invertebrate and fish harvested species was supported by data for the fish species and partially supported for invertebrates. However, well-managed TURFs indeed enhanced the biomass of the most important commercial invertebrate species, such as abalone and lobster, indicating that well-managed TURFs are an effective tool for conserving harvested marine species. Our results are relevant not only for Baja California but also for global conservation efforts, including discussions around OECMs, the 30×30 target, and Mexico's emerging National Restoration Plan. By showing that well-managed TURFs can generate benefits comparable to MPAs, our work contributes to the growing body of evidence that these spatial management systems can serve both fisheries and conservation objectives. Importantly, our results do not imply that cooperatives are the only viable model, but rather that the governance attributes they embody, secure access, stewardship, and continuity, can support effective management across diverse social contexts. Ultimately, strengthening marine and coastal governance is a shared responsibility between local users and regional and national institutions, and is essential for achieving resilient coastal ecosystems and sustainable fisheries.

6. CONCLUSIONES (Español)

Nuestro trabajo aporta evidencia de que los TURFs con alta capacidad de cumplimiento pueden generar beneficios sustanciales para los ecosistemas costeros. Nuestra hipótesis de que los TURFs bien manejados sostendrían una mayor biomasa de especies explotadas de invertebrados y peces fue respaldada por los datos para las especies de peces y apoyada parcialmente para los invertebrados. No obstante, los TURFs bien manejados sí incrementaron la biomasa de las especies de invertebrados comerciales más importantes, como el abulón y la langosta, lo que indica que los TURFs bien manejados son una herramienta eficaz para la conservación de especies marinas explotadas. Nuestros resultados son relevantes no solo para Baja California, sino también para los esfuerzos de conservación a nivel global, incluyendo las discusiones en torno a las OECMs, la meta 30×30 y el emergente Plan Nacional de Restauración de México. Al demostrar que los TURFs bien manejados pueden generar beneficios comparables a los de las Áreas Marinas Protegidas, nuestro trabajo contribuye al creciente cuerpo de evidencia que muestra que estos sistemas de manejo espacial pueden servir simultáneamente a los objetivos de las pesquerías y de la conservación. Es importante destacar que nuestros resultados no implican que las cooperativas sean el único modelo viable, sino que los atributos de gobernanza que encarnan, como el acceso seguro, custodia y continuidad, pueden sustentar un manejo efectivo en diversos contextos sociales. En última instancia, el fortalecimiento de la gobernanza marina y costera es una responsabilidad compartida entre los usuarios locales y las instituciones regionales y nacionales, y es esencial para lograr ecosistemas costeros resilientes y pesquerías sostenibles.

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8. SUPPLEMENTARY MATERIAL

Table S1. Fish species of commercial interest regulated under national management plans and included in biomass analyses across management categories. Species in bold represent the two focal species selected because their latitudinal distributions lie within the central portion of our study area (~29.5°N).

Species
Bodianus pulcher
Calamus brachysomus
Caulolatilus princeps
Cheilotrema saturnum
Heterodontus francisci
Hypanus dipterurus
Mycteroperca xenarcha
Myliobatis californica
Ophiodon elongatus
Paralabrax clathratus
Paralabrax nebulifer
Paralichthys californicus
Scorpaena guttata
Sebastes atrovirens
Sebastes auriculatus
Sebastes carnatus
Sebastes caurinus
Sebastes chrysomelas
Sebastes miniatus
Sebastes rastrelliger
Sebastes serranoides
Sebastes serriceps
Seriola lalandi
Sphoeroides lobatus
Sphyraena argentea
Stereolepis gigas
Urobatis halleri
Zapteryx exasperata

Table S2. Species-specific mean body mass of macroinvertebrates used to derive biomass estimates, based on Olguín-Jacobson et al. (2025) and Fajardo-León et al. (2008).

Species	Mass (kg)
Panulirus interruptus	1
Haliotis spp.	0.25
Mesocentrotus franciscanus	0.4
Megastraea spp	0.4
Apostichopus parvimensis	0.25

Table S3. Centroids of latitudinal distribution ranges of the five key commercially important invertebrates within TURFs and nationally managed fish species in Baja California, based on FishBase records.

Species	Maximun latitude	Minimum latitude	Centroid
Invertebrates			
Panulirus interruptus	34° N	25° N	29.5° N
Haliotis spp	34° N	25° N	29.5° N
Mesocentrotus franciscanus	57° N	28° N	42° N
Megastraea spp	34° N	27° N	29° N
Apostichopus parvimensis	34° N	26° N	30° N
Fish			
Bodianus pulcher	36° N	22° N	29.5° N
Paralabrax chlathratus	48° N	23° N	35.5° N

Table S4. Management categories assigned to each ecological monitoring site, based on fisheries data for key benthic commercial species obtained from Mexico's National Transparency Platform and validated through consultation with key actors.

Site	Category
Baja Mar	Permit
Campo Lopez	Permit
Bajo Coronado	Permit
Isla Todos Santos Protegido	Mixed
Isla Todos Santos Expuesto	Mixed
Punta Banda	Mixed
El Retiro	Mixed
Salsipuedes	Permit
San Miguel	Mixed
La Bocana	Mixed
Isla San Martin Expuesto	Mixed
Isla San Martin Protegido	Mixed
El Rosario Picacho	Concession
El Rosario Lazaro	Concession
Isla San Jeronimo Expuesto	Concession
Arrecife Sacramento	Permit
Islas San Benitos El Tecapan	Concession
Isla Cedros La Botella	Concession
Isla Cedros Puerto Escondido	Concession
Isla Cedros Punta Norte	Concession
Isla Cedros Cabo San Agustin	Concession
Punta Eugenia El Reventon	Concession
Punta Eugenia Las Boyas	Concession
Isla Natividad El Tibo	Concession
Isla Natividad La Vela	Concession
Bahia Tortugas Sargacera	Concession
Bahia Tortugas Clambei	Concession
Emancipación Puerto Escondido	Concession
Emancipación El Cardon	Concession
Punta San Roque	Concession
Isla Asuncion	Concession

Table S5. Expert survey knowledge

TURF Category	**No. of Sites**	**Surveillance**	**Monitoring (frequency)**	**User type**
Permit	5	Abscent	Goverment (inconsistent)	Temporary employees
Mixed	8	Abscent	Goverment (inconsistent)	Temporary employees
Cooperative	19	Continuous (24/7)	Coopertive (annual)	Members

Table S6. Dufrene-Legendre Indicator Species Analysis to distinguish which species were contributing to significant clusters identified by the post-hoc tests for invertebrates.

Species	**Indicator Value**	**P-value**
Inverts	**North**	
Urticina mcpeaki	0.7787	0.001
Styela monterreyensis	0.7071	0.001
Strongylocentrotus purpuratus	0.9439	0.001
Pisaster ochraceus	0.4663	0.004
Pisaster giganteus	0.8020	0.001
Patiria miniata	0.9868	0.001
Pachycerianthus fimbriatus	0.4170	0.008
Ophiura sp	0.3612	0.022
Norrisia norrisii	0.6604	0.002
Mesocentrotus franciscanus	0.9674	0.001
Lytechinus anamesus	0.7372	0.001
Kelletia kelletii	0.9493	0.001
Henricia leviuscula	0.7214	0.002
Cypraea spadicea	0.8058	0.001
Crassedoma giganteum	0.6955	0.019
Apostichopus parvimensis	0.7137	0.004
Apostichopus californicus	0.3612	0.021
Anthopleura elegantissima	0.7168	0.003
Anthopleura artemisa	0.3297	0.046
	South	
Acarnus erithacus	0.7963	0.001
Centrostephanus coronatus	0.8948	0.001
Eucidaris thouarsii	0.9874	0.001
Haliotis sp	0.9589	0.001
Leptogorgia chilensis	0.6131	0.001
Linckia columbiae	0.6892	0.001
Megastraea sp	0.7995	0.001
Muricea californica	0.9575	0.001
Muricea fruticosa	0.7867	0.001
Panulirus interruptus	0.9526	0.001
Spheciospongia confoederata	0.7334	0.002
Pacifigorgia sp	0.4743	0.003
Craniella arb	0.3417	0.038
Phataria unifascialis	0.3162	0.038

Table S7. Dufrene-Legendre Indicator Species Analysis to distinguish which species were contributing to significant clusters identified by the post-hoc tests for fish

Species	Indicator Value	P-value
Fish	**North**	
Chromis punctipinnis	0.7810	0.001
Embiotoca jacksoni	0.7313	0.025
Embiotoca lateralis	0.5054	0.003
Hypsurus caryi	0.4319	0.04
Ophiodon elongatus	0.4663	0.005
Oxyjulis californica	0.8615	0.001
Oxylebius pictus	0.9359	0.001
Rhacochilus toxotes	0.4620	0.028
Rhacochilus vacca	0.6392	0.001
Rhinogobiops nicholsii	0.7372	0.001
Scorpaenichthys marmoratus	0.3901	0.017
Sebastes atrovirens	0.8245	0.001
Sebastes auriculatus	0.6884	0.001
Sebastes carnatus	0.5517	0.001
Sebastes caurinus	0.5108	0.002
Sebastes chrysomelas	0.5898	0.001
Sebastes serranoides	0.4935	0.004
Sebastes serriceps	0.5898	0.001
	South	
Anisotremus davidsonii	0.6359	0.001
Calamus brachysomus	0.3627	0.019
Girella nigricans	0.7511	0.001
Halichoeres semicinctus	0.9132	0.001
Heterodontus francisci	0.5130	0.001
Heterostichus rostratus	0.4291	0.01
Lythrypnus dalli	0.5380	0.001
Medialuna californiensis	0.6954	0.001
Paralabrax clathratus	0.8310	0.001
Stegastes rectifaenum	0.3627	0.018
Urobatis halleri	0.5380	0.001
Zapteryx exasperata	0.5812	0.002

Table S8. PERMANOVA results for the invertebrate community (n = 55 species) comparing northern vs. southern subregions (Bray–Curtis; 999 permutations).

	Df	SS	R^2	F	*p* value
Model	1	8.252970977	0.531148191	95.16108765	0.001
Residual	84	7.285010913	0.468851809		
Total	85	15.53798189	1		

Table S9. PERMANOVA results for the fish community (n = 76 species) comparing northern vs. southern subregions (Bray–Curtis; 999 permutations).

	Df	SS	R^2	F	*p* value
Model	1	3.017112957	0.29994092	35.13297108	0.001
Residual	82	7.041911198	0.70005908		
Total	83	10.05902416	1		

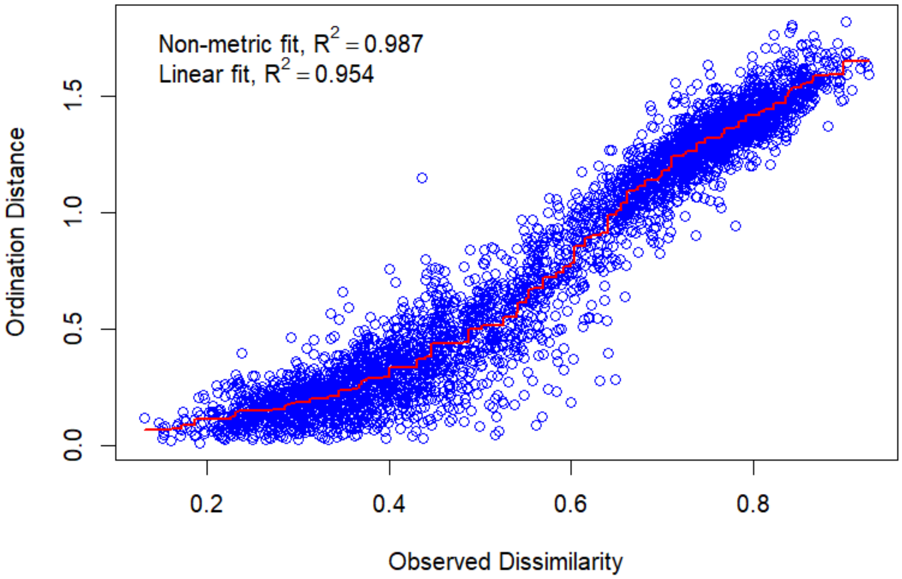

Figure S1. Invertebrates' community NMDS Stress plot

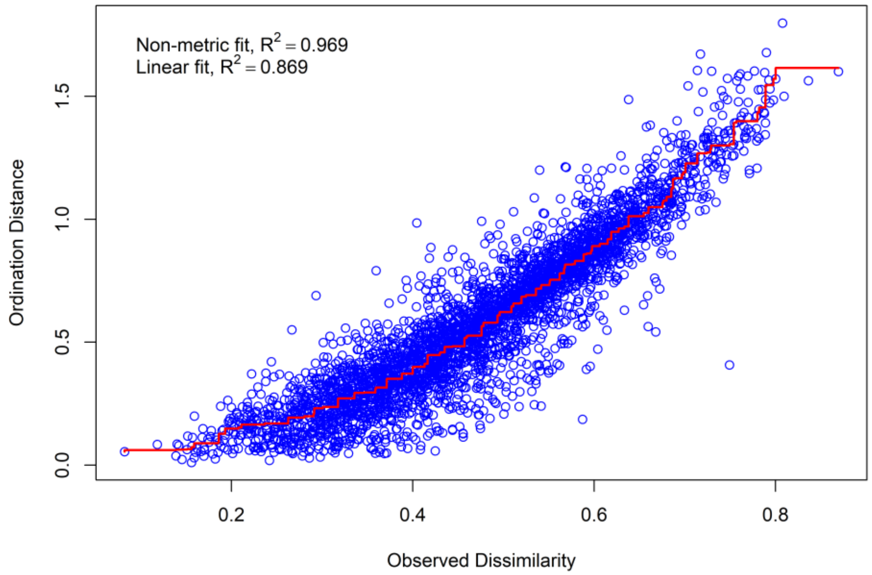

Figure S2. Fish community NMDS Stress plot

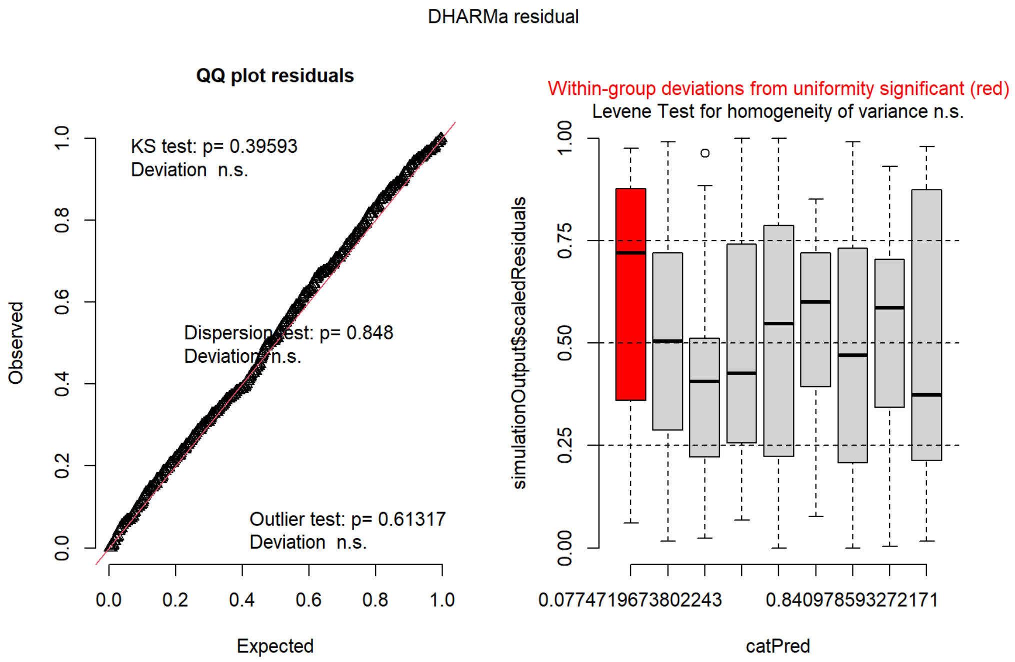

Figure S3. Diagnostic plot for the invertebrate's assemblage GLMM.

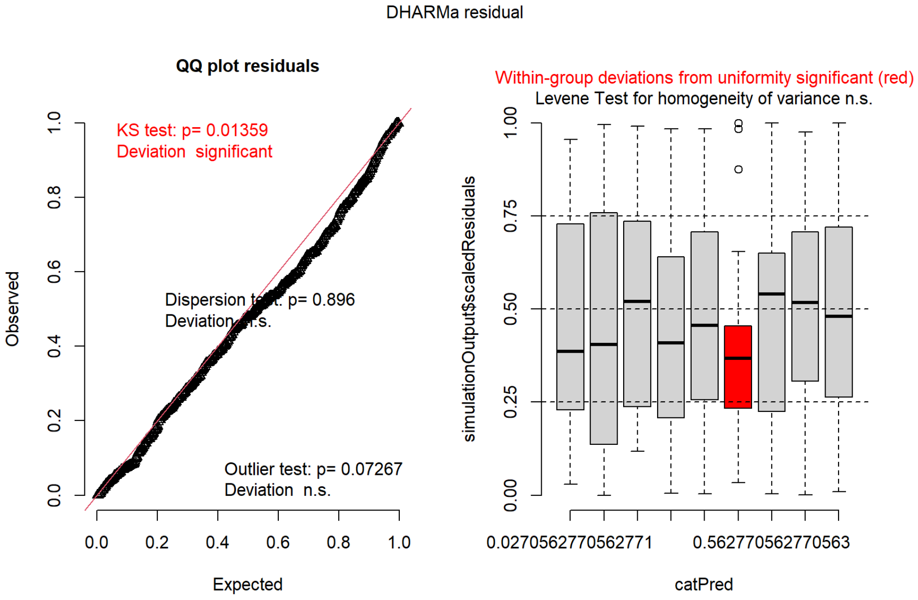

Figure S4. Diagnostic plot for lobster GLMM

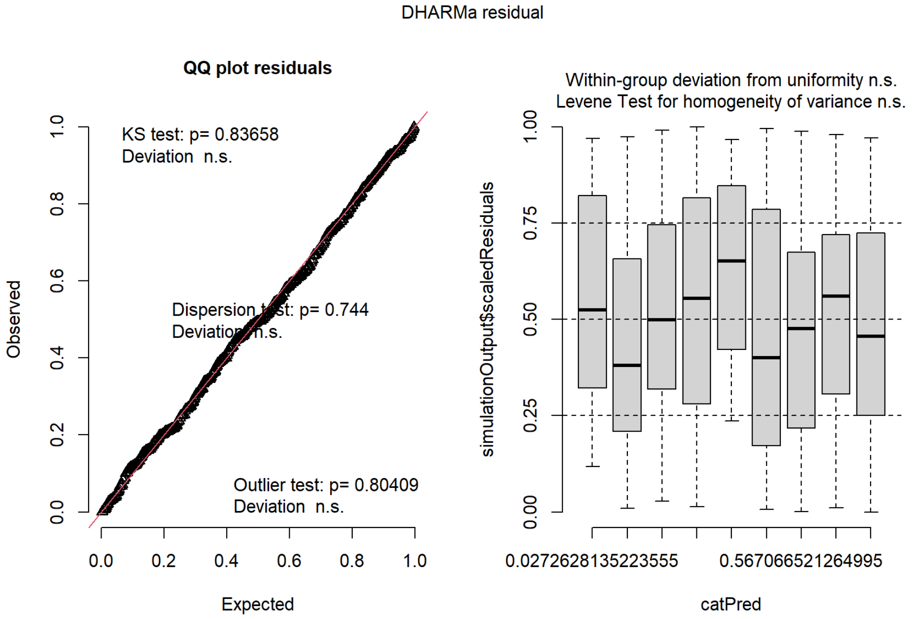

Figure S5. Diagnostic plot for the abalone GLMM

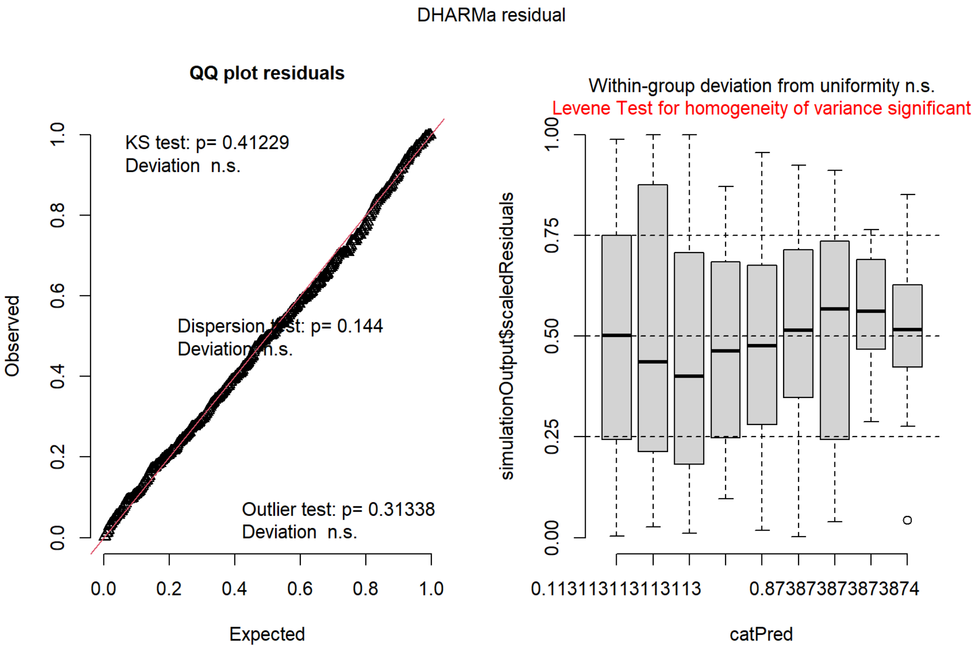

Figure S6. Diagnostic plot for the red sea urchin GLMM

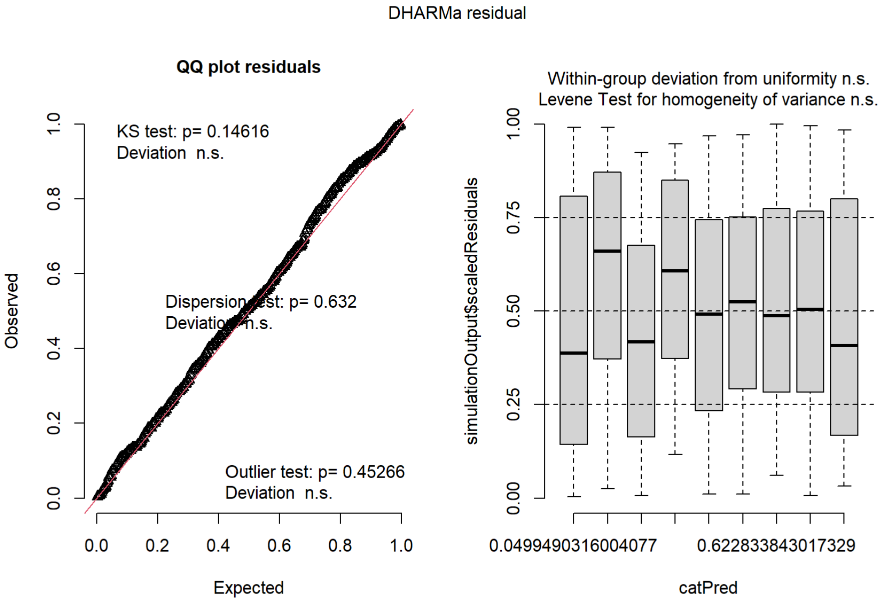

Figure S7. Diagnostic plot for the sea snail GLMM

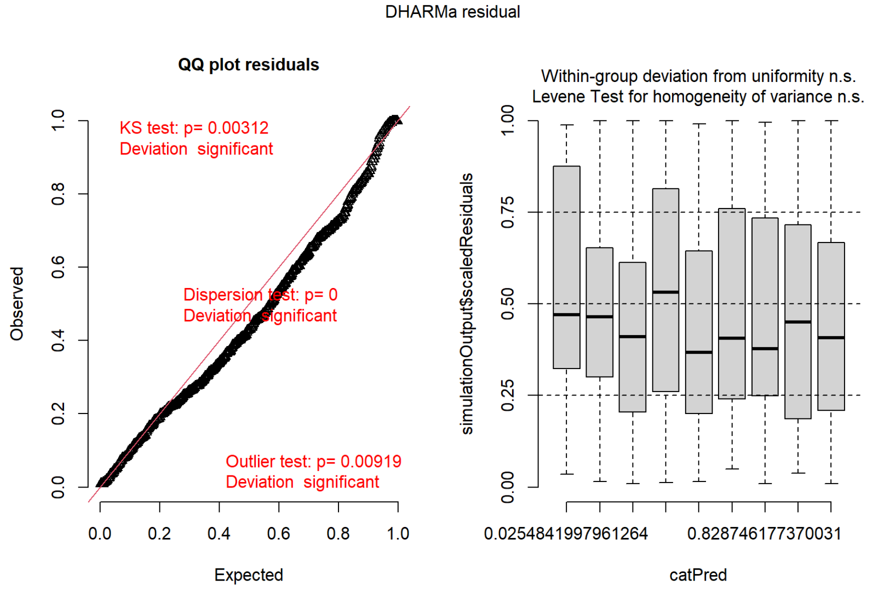

Figure S8. Diagnostic plot for sea cucumber GLMM

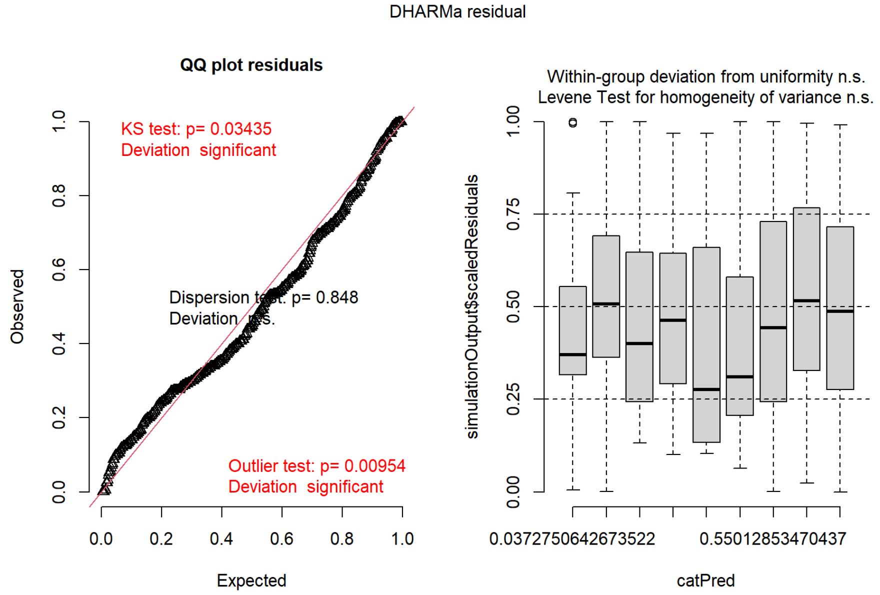

Figure S9. Diagnostic plot for the fish assemblage GLMM.

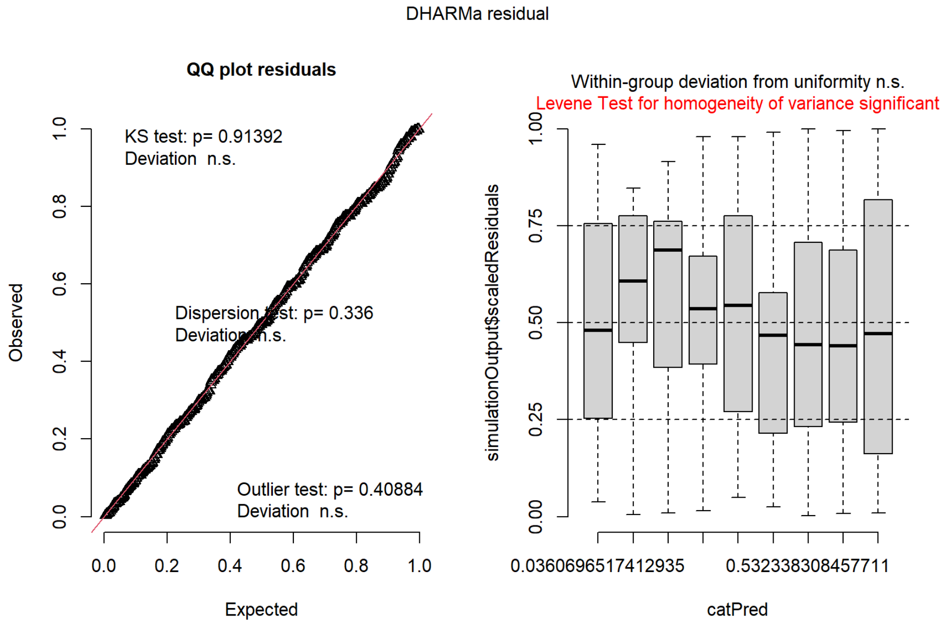

Figure S10. Diagnostic plot for the California sheephead assemblage GLMM.

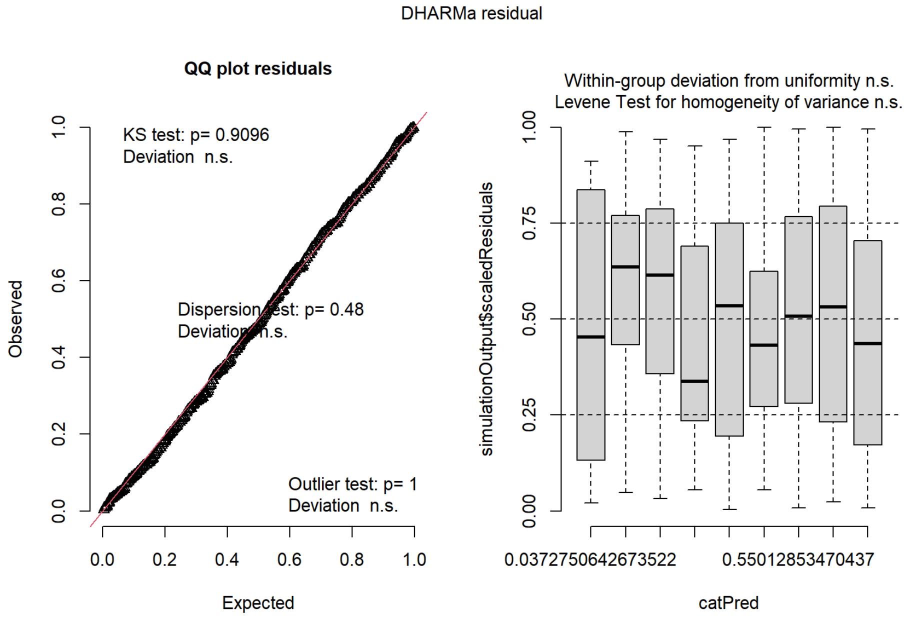

Figure S11. Diagnostic plot for the kelp bass GLMM.