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Marine conservation across political borders

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# Marine conservation across political borders

A dissertation submitted in partial satisfaction of the requirements for the degree
Doctor of Philosophy in

Marine Biology

by

Juan Arturo Ramírez-Valdez

Committee in charge:

Professor Marco Octavio Aburto Oropeza, Chair
Professor Exequiel Ezcurra, Co-Chair
Professor Edward P. Parnell
Professor Philip Hastings
Professor Richard Carson

2020

The Dissertation of Juan Arturo Ramírez Valdez is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Co-chair

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University of California San Diego

2020

# DEDICATION

I dedicate this dissertation to my parents, Eduardo, and Yolanda.

Because everything starts with a loving family.

# EPIGRAPH

“Any fool can know. The point is to understand.”

Albert Einstein

For love of domination we must substitute equality;

for love of victory we must substitute justice;

for brutality we must substitute intelligence;

for competition we must substitute cooperation.

We must learn to think of the human race as one family.

Bertrand Russell

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Nava, S. Fulton, L.M. Cavole, B. Semmens, K. Blincow, A. Castillo, H.M. Sue, M.P. Sgarlatta, A. Gomez-Gomez, R. Domínguez-Reza, O. Santana-Morales, T. Winquist, B. Fiscella, O. Sosa-Nishizaki, I. Giffard-Mena, I. Mascareñas-Osorio, L. Castillo-Geniz, M. Ramade, J. Castro, T. Camacho-Bareño, M.A. Bracamontes, E. Enriquez.

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Chapter 3, in full, is a preprint of the material as it appears in UC Office of the President: UC-Mexico Initiative 2017. **Ramírez-Valdez A.,** O. Aburto-Oropeza, N. Arafeh Dalmau, R. Beas-Luna, J.E. Caselle, M.C.N. Castorani, K. Cavanaugh, M. Edwards, G. Hernández-Carmona, A.F. Johnson, H.M. Leslie, G. Montaño-Moctezuma, F. Micheli, J. Palleiro Nayar, P.E. Parnell, D.C. Reed, O. Sosa-Nishizaki, J. Torre, G. Torres Moye, J.A. Zertuche-González, P. Raimondi. 2017. Mexico-California bi-national initiative of kelp forest ecosystems and fisheries. White paper prepared for UC-Mexico Initiative. 48p. The dissertation author was the primary investigator and author of this material.

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# PUBLICATIONS

Valencia-Méndez O., Rodriguez-Zaragoza F.A., Palacios-Salgado D.S., Ramírez-Valdez A., Lopez-Perez A., Reef-associated fishes from the southern Mexican Pacific. Marine Biodiversity. Submitted.

Dale K.E., Ramírez-Valdez A., McCosker J., Love M. New evidence for an old problem: Revising geographic distributions of Eastern Pacific moray eels. B. Marine Science. Submitted.

Aburto-Oropeza O., Johnson A.F., Ramírez-Valdez A., and 94 coauthors in alphabetical order. 2018. Harnessing Cross-border Resources to Confront Climate Change. Environmental Science and Policy. 87: 128-132.

Ramírez-Valdez A.*, Aburto-Oropeza O., 18 coauthors, and Raimondi P. 2017. Mexico-California bi-national initiative of kelp forest ecosystems and fisheries. White paper prepared for UC-Mexico Initiative. 48p.

Cavole L.M., Demko A.M., Diner R.E, Giddings A., Koester I., Pagniello C.M.L.S., Paulsen M., Ramírez-Valdez A., Schwenck S., Yen N., Zill M.E., Franks P. 2016. Biological impacts of 2013-2015 Warm Water Anomalies in the Northeast Pacific: Winners, Losers and the Future. Oceanography.

Ramírez-Valdez A.*, Dominguez-Guerrero I., Palacios-Salgado D., Villaseñor-Derbez J.C., Cota-Nieto J.J., Correa-Sandoval F., Reyes-Bonilla H., Hinojosa-Arango G., Hernández A.,

Aburto-Oropeza O. 2015. The near-shore fishes of the Cedros Archipelago (North-Eastern Pacific) and their biogeographic affinities. CalCOFI Reports 56, 143-167.

Palacios Salgado D.S., Ramírez-Valdez, A.*, Rojas Herrera A., Melo, M.A. 2014. Marine Fishes of Acapulco, Mexico (Eastern Pacific Ocean). Marine Biodiversity 44(4): 471-490.

Palacios-Salgado D.S., Burnes-Romo L.A., Tavera-Vargas J.J., Ramírez-Valdez A. 2012. Endemic fishes of the Cortez biogeographic province. Acta Ichthyologica et Piscatoria. 42(29):153-164.

Aguilar-Rosas L., Correa-Sandoval F., Ramírez-Valdez A., Giffard-Mena I., Aguilar-Rosas C. 2011. First record of *Dictyopteris prolifera* (Okamura) Okamura (Dictyotales, Phaeophyceae) on the Eastern Pacific coast. Marine Biodiversity Records 4:1-5.

Palacios-Salgado D.S., Ramírez-Valdez A., Ruiz-Campos G. 2011. First record and establishment of the exotic poecilid, *Poecilia butleri* (Teleostei: Poeciliidae) in the Baja California Peninsula, Mexico. California Fish & Game 97(2): 98-103.

Palacios-Salgado D.S. & A. Ramírez-Valdez. 2011. New records of demersal fishes in the Northwest of Mexico. J. Fisheries and Aquatic Science. 6(1):93-100.

Ruiz-Campos G., A. Ramírez-Valdez, S. González-Guzmán, J.L. Castro-Aguirre, A.F. González-Acosta & J. De La Cruz-Agüero. 2010. Composition, density and biogeographic affinities of the rocky intertidal fishes on the western coast of the Baja California peninsula, Mexico. CalCOFI Rep. Vol. 51: 210-220

Reyes-Bonilla H., Calderón-Aguilera L.E., Y. Bedolla-Guzmán, A. Ayala-Bocos, A. Ramírez-Valdez, I. Sánchez, S. González-Romero. 2010. Checklist and biogeography of fishes from Guadalupe island, western Mexico. CalCOFI Rep. Vol. 51: 195-209.

Ruiz-Campos G., A. Ramírez-Valdez, S. González-GuzmánGonzález-Acosta A., D. Acosta Zamorano. 2010. Length-weight and length-length relationships for nine rocky tide pool fishes from Pacific coast of the Baja California peninsula, México. J. Appl. Ichthyol. 26(1):118-119.

Palacios Salgado D.S., Ramírez-Valdez A., Rojas Herrera A. 2008. First record of *Acanthurus nigricans* (Perciformes: Acanthuridae) and *Catherines dumerilii* (Monacanthidae) in Guerrero coast, Mexico. Mar Biod. Rec, 2008(1): 1-2.

## AWARDS, FELLOWSHIPS AND RESEARCH GRANTS

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## FIELD OF STUDY

Major Field: Marine Biology, Marine Conservation, Fisheries.

# ABSTRACT OF THE DISSERTATION

## Marine conservation across political borders

by

Juan Arturo Ramírez Valdez

Doctor of Philosophy in Marine Biology

University of California San Diego, 2019

Professor Octavio Aburto Oropeza, Chair
Professor Exequiel Ezcurra, Co-Chair

In the marine environment, political borders are essentially imaginary lines that often divide well-connected populations, communities and habitats. Scientific evidence shows that collaboration among nations can improve the effectiveness of program management, conservation, and cost efficiency. Despite the evidence that the marine region between California (U.S.) and Baja California (Mexico) constitutes a single ecoregion, our research revealed a lack of binational collaboration and differences in knowledge, and management of trans-boundary marine species. Chapter 1 asks what the fish composition of the Cedros archipelago is, and if the affinity of the species would allow us to recognize the biogeographic break between the temperate and subtropical systems. We found that the Cedros archipelago fish community is a species-rich assemblage, with a fairly even blend of temperate and tropic-subtropical affinity species and

represents a marked break between the San Diegan and the Cortez biogeographic provinces. We recorded nineteen new species occurrences in the Cedros archipelago, and limited sampling effort south of the U.S.-Mexico border may be the most likely reason for these new occurrences. Chapter 2 asks whether asymmetric management of marine resources across socio-political borders could result in loss of economic opportunities and threaten populations through overfishing. In the case of the critically endangered giant sea bass we found that extremely strong asymmetry exists in scientific knowledge, economic input, and conservation across the U.S.-Mexico border, political regulations have both hidden and created illusions of false historical population collapses, and the total population size is likely higher than previously estimated. In the case of the economic value of the giant kelp forest we found a positive relationship between kelp forest cover and the fisheries production, the higher the kelp cover, the higher the fishery production, and therefore the revenues resulting from them. Chapter 3 aims to analyze the effects of climate change in the giant kelp forest ecosystem across the U.S.-Mexico border and what the future scenario would be in the face of the current climatic trends. Our literature review showed that the giant kelp and the biological communities it supports will likely react to climatic and non-climatic changes in complex ways, likely by contracting their southern extent due to warming waters, reductions in nutrient availability, increasing wave disturbance, and grazing by warm-water herbivores. As a result, the best strategy in the long run is transboundary cooperation through sharing cross-border marine resources and acknowledging the actions taken by one of the invariable parties affects the other. Our results highlight the need for greater cross-border cooperation in conservation and marine resources management and generate research political-borderless.

# INTRODUCTION

Marine conservation strategies are commonly aimed at limiting human-induced impacts, restoring damaged marine ecosystems, and preserving vulnerable species (Duarte et al., 2020; Knowlton, 2020; Worm, 2017). For this reason, the design and implementation of marine conservation strategies require multi-factor analysis, which can be even more complicated when considering the resources being shared by nations. In marine ecosystems, cooperation and coordination between countries are especially important because of ocean currents and the natural flow of material in the sea, the high mobility and dispersion of species, the maintenance of genetic flow in the populations, the common use of marine resources, and marine sovereignty (Levin et al., 2013).

In marine environments, political borders are intangible lines that often divide well-connected populations, communities, and habitats (Block et al., 2011; Selkoe et al., 2010). While biogeographic boundaries are the result of the natural distribution of species, political boundaries are artifacts of human organization that tend to delineate the limits of decision-making processes (Dallimer and Strange, 2015). When nations share species and ecosystems, they also share the ecosystem services that maintain human life (López-Hoffman et al., 2010). The identification of the spatial areas of species and ecosystems is relevant for the establishment of adequate and representative conservation strategies, especially in ecosystems shared across nations. Additionally, scientific evidence shows that collaboration among nations can improve management and conservation program effectiveness and cost efficiency by developing a fully coordinated plan that encompasses protected area and conservation goals (Kark et al., 2009).

Despite the evidence that the marine region between California, United States (U.S.), and Baja California, Mexico, constitutes a single marine ecoregion (Horn et al., 2006; Pondella et al., 2005), research efforts have revealed a lack of binational collaboration and differences in knowledge, conservation, and management of trans-boundary marine species (Aburto-Oropeza et al., 2018; Wilder, 2013). The U.S. and Mexico together account for more than 2,600 km of coastline in the temperate sea of the Northeastern Pacific, which hosts a huge diversity of species ranging from local resident populations important for sustaining food webs, such as giant kelp (Macrocystis pyrifera) (Edwards and Hernandez-Carmona, 2005), to large predators and other mobile organisms that cross the national border regularly, such as sharks and giant sea bass (Stereolepis gigas) (Block et al., 2011; Chabot et al., 2015). In the Northeastern Pacific, giant kelp forms dense forests from Santa Cruz, California (U.S.) to Bahia Asuncion, Baja California Sur (Mexico). Giant kelp forests can be considered the submerged counterparts of rain forests and are among the most species-rich communities (Schiel and Foster, 2015) and productive ecosystems on earth (Reed et al., 2015). Giant kelp is an ecosystem engineer that creates biogenic habitats that provide refuge for numerous species, including many that are often economically important for fisheries (P. Edward Parnell et al., 2010; Schiel and Foster, 2015).

The kelp forest communities of the Northeastern Pacific have experienced two very different histories. Along the coast of California, a long history of fishing pressure (M. J. M. J. Tegner and Dayton, 2000), continuous long-term scientific monitoring programs (Foster et al., 2013; Schiel and Foster, 2015; Tegner and Dayton, 1987), and networks of marine reserves (Murray and Hee, 2019) all highlight the high quantity of coastal human impacts both positive and negative for the ecosystem. Contrastingly, the kelp forests off the coast of the Baja California Peninsula lack a marine reserve network established along the coastline and have received much less attention from both large-scale fisheries and research and monitoring initiatives (Arafeh-Dalmau et al., 2017). Along the Baja California Peninsula and Southern California, the presence and abundance of kelp is very dynamic in space and time as a result of grazing, storms, episodic oceanographic events, and climate change (Arafeh-Dalmau et al., 2017; Cavanaugh et al., 2019; P. Ed Parnell et al., 2010). In addition to natural and anthropic stressors, coastal marine ecosystems around the world and the human communities that depend on them are facing the challenge of an increasingly variable climate. (Doney et al., 2012; Hoegh-Guldberg and Bruno, 2010). The pressure that these stressors pose to the marine ecosystem has generated habitat alteration and an increase of species vulnerability (Hoegh-Guldberg and Bruno, 2010).

The existence of four research pathways has been suggested (Dallimer and Strange, 2015), which may enhance our ability to address the adverse effects of socio-political borders on conservation: (i) scale-matching, (ii) quantification of the mutual economic benefits of conservation across boundaries, (iii) determining transboundary societal values, and (iv) acknowledging the importance of stakeholder behavior and incentives. This work addresses these research pathways, involving marine resources of ecological importance and economic value in the California (U.S.) and Baja California Peninsula (Mexico) region, and incorporating a wide range of stakeholders.

Building upon existing information and generating new evidence, my research incorporates different sources of observational data to develop and propose new conservation strategies in the management of marine resources from a transboundary perspective. The following specific questions guide each chapter of this thesis: *How do socio-political barriers operate to restrict the* *knowledge we have of marine resources? What are the ecological and economic implications as a result of differential use and management of marine resources across socio-political boundaries? How does climate change impact the conservation and management of trans-boundary marine resources?*

The goals of this dissertation were to assess the asymmetry in knowledge and management of marine resources across the U.S.-Mexico political border, using the distribution of fish species, the differential management of the giant sea bass (*Stereolepis gigas*), the economic value of the giant kelp (*Macrocystis pyrifera*) forest ecosystem, and the implications of climate change for the future scenario of kelp forests across the border as indicators. Using fish distributions as a case study, the objectives for Chapter 1 were to analyze the implications of the uncertainty of the species distribution in the transition between the warm-temperate and subtropical real. The objectives of Chapter 2 were to evaluate the ecological and economic implications of the differential management of marine resources across socio-political boundaries. To that end, I developed two case studies. For the first case study, I analyzed the asymmetry in the management of a critically endangered fish species across the political border between the U.S. and Mexico. For the second case study, I examined the ecological and economic value of the kelp forest ecosystem and the services it provides using commercially important species that rely on this ecosystem. The objectives of Chapter 3 were to analyze the effects of climate change in the giant kelp forest ecosystem across the U.S.-Mexico border and what the future scenario would be in the face of the current climatic trends. To do this, I developed a literature review to compile the existing knowledge about the giant kelp forest ecosystems in California (U.S.) and Baja California (Mexico). The collection of research identifies the importance of how political boundaries can represent a challenge for some marine resources, in the same way as it has been documented with the terrestrial system (López-Hoffman et al., 2010; Wilder, 2013).

# REFERENCES

Aburto-Oropeza, O., Johnson, A.F., Agha, M., Allen, E.B., Allen, M.F., González, J.A., Arenas Moreno, D.M., Beas-Luna, R., Butterfield, S., Caetano, G., Caselle, J.E., Gaytán, G.C., Castorani, M.C.N., Cat, L.A., Cavanaugh, K., Chambers, J.Q., Cooper, R.D., Arafeh-Dalmau, N., Dawson, T., de la Vega Pérez, A.D., DiMento, J.F.C., Guerrero, S.D., Edwards, M., Ennen, J.R., Estrada-Medina, H., Fierro-Estrada, N., Gadsden, H., Galina-Tessaro, P., Gibbons, P.M., Goode, E. V., Gorris, M.E., Harmon, T., Hecht, S., Heredia Fragoso, M.A., Hernández-Solano, A., Hernández-Cortés, D., Hernández-Carmona, G., Hillard, S., Huey, R.B., Hufford, M.B., Jenerette, G.D., Jiménez-Osornio, J., López-Nava, K.J., Lara Reséndiz, R.A., Leslie, H.M., López-Feldman, A., Luja, V.H., Méndez, N.M., Mautz, W.J., Medellín-Azuara, J., Meléndez-Torres, C., de la Cruz, F.R.M., Micheli, F., Miles, D.B., Montagner, G., Montaño-Moctezuma, G., Müller, J., Oliva, P., Ortinez Álvarez, J.A., Ortiz-Partida, J.P., Palleiro-Nayar, J., Páramo Figueroa, V.H., Parnell, P.E., Raimondi, P., Ramírez-Valdez, A., Randerson, J.T., Reed, D.C., Riquelme, M., Torres, T.R., Rosen, P.C., Ross-Ibarra, J., Sánchez-Cordero, V., Sandoval-Solis, S., Santos, J.C., Sawers, R., Sinervo, B., Sites, J.W., Sosa-Nishizaki, O., Stanton, T., Stapp, J.R., Stewart, J.A.E., Torre, J., Torres-Moye, G., Treseder, K.K., Valdez-Villavicencio, J., Valle Jiménez, F.I., Vaughn, M., Welton, L., Westphal, M.F., Woolrich-Piña, G., Yunez-Naude, A., Zertuche-González, J.A., Taylor, J.E., 2018. Harnessing cross-border resources to confront climate change. Environ. Sci. Policy 87, 128–132. https://doi.org/10.1016/j.envsci.2018.01.001

Arafeh-Dalmau, N., Torres-Moye, G., Seingier, G., Montaño-Moctezuma, G., Micheli, F., 2017. Marine Spatial Planning in a Transboundary Context: Linking Baja California with California's Network of Marine Protected Areas. Front. Mar. Sci. 4, 1–14. https://doi.org/10.3389/fmars.2017.00150

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M., 2008. Economic valuation for the conservation of marine biodiversity. Mar. Pollut. Bull. 56, 386–396. https://doi.org/10.1016/j.marpolbul.2007.11.013

Bell, T.W., Cavanaugh, K.C., Reed, D.C., Siegel, D.A., 2015. Geographical variability in the controls of giant kelp biomass dynamics. J. Biogeogr. 42, 2010–2021. https://doi.org/10.1111/jbi.12550

Block, B.A., Jonsen, I.D., Jorgensen, S.J., Winship, A.J., Shaffer, S.A., Bograd, S.J., Hazen, E.L., Foley, D.G., Breed, G.A., Harrison, A.L., Ganong, J.E., Swithenbank, A., Castleton, M., Dewar, H., Mate, B.R., Shillinger, G.L., Schaefer, K.M., Benson, S.R., Weise, M.J., Henry, R.W., Costa, D.P., 2011. Tracking apex marine predator movements in a dynamic ocean.

Nature 475, 86–90. https://doi.org/10.1038/nature10082

Caddy, J.F., 1997. Establishing a consultative mechanism or arrangement for managing shared stocks within the jurisdiction of contiguous states, in: Taking Stock: Defining and Managing Shared Resources. Australian Society for Fish Biology and Aquatic Resource Management Association of Australasia Joint Workshop Proceedings, p. 16.

Cavanaugh, K.C., Reed, D.C., Bell, T.W., Castorani, M.C.N., Beas-Luna, R., 2019. Spatial variability in the resistance and resilience of giant kelp in southern and Baja California to a multiyear heatwave. Front. Mar. Sci. 6, 1–14. https://doi.org/10.3389/fmars.2019.00413

Cavanaugh, K.C., Siegel, D.A., Reed, D.C., Dennison, P.E., 2011. Environmental controls of giant-kelp biomass in the Santa Barbara Channel, California. Mar. Ecol. Prog. Ser. 429, 1–17. https://doi.org/10.3354/meps09141

Cavole, L.M., Demko, A.M., Diner, R.E., Giddings, A., Koester, I., Pagniello, C.M.L.S., Paulsen, M.-L., Ramirez-Valdez, A., Schwenck, S.M., Yen, N.K., Zill, M.E., Franks, P.J.S., 2016. Biological impacts of the 2013–2015 warm-water anomaly in the northeast Pacific: Winners, Losers, and the Future. Oceanography 29. https://doi.org/10.5670/oceanog.2016.32

Chabot, C.L., Hawk, H.A., Allen, L.G., 2015. Low contemporary effective population size detected in the Critically Endangered giant sea bass, Stereolepis gigas, due to fisheries overexploitation. Fish. Res. 172, 71–78. https://doi.org/10.1016/j.fishres.2015.06.015

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R.G., Sutton, P., Van Den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260. https://doi.org/10.1038/387253a0

Dallimer, M., Strange, N., 2015. Why socio-political borders and boundaries matter in conservation. Trends Ecol. Evol. 30, 132–139. https://doi.org/10.1016/j.tree.2014.12.004

Dayton, P.K., Tegner, M.J., Edwards, P.B., Riser, K.L., 1998. Sliding baselines, ghosts, and reduced expectations in kelp forest communities. Ecol. Appl. 8, 309–322. https://doi.org/10.1890/1051-0761(1998)008[0309:SBGARE]2.0.CO;2

Dayton, P.K.P., 1985. Ecology of kelp communities. Annu. Rev. Ecol. Syst. 16, 215–245.

Domeier, M., 2001. Giant Sea Bass. California's Mar. Living Resour. A Status Rep. 209–211.

Doney, S., Ruckelshaus, M., Duffy, J., Barry, J., Chan, F., 2012. Climate change impacts on marine ecosystems.

Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.P., Fulweiler, R.W., Hughes, T.P., Knowlton, N., Lovelock, C.E., Lotze, H.K., Predragovic, M., Poloczanska, E., Roberts, C., Worm, B., 2020. Rebuilding marine life. Nature. https://doi.org/10.1038/s41586-020-2146-7

Edwards, M.S., Hernandez-Carmona, G., 2005. Delayed recovery of giant kelp near its southern range limit in the North Pacific following El Nino. Mar. Biol. 147, 273–279. https://doi.org/10.1007/s00227-004-1548-7

Edwards, M.S.M., Estes, J.A., 2006. Catastrophe, recovery and range limitation in NE Pacific kelp forests: a large-scale perspective. Mar. Ecol. Prog. Ser. 320, 79–87. https://doi.org/10.3354/meps320079

Erisman, B.E., Allen, L.G.L., Claisse, J.J.T., Pondella, D.J., Miller, E.F., Murray, J.H., Pondella II, D.J., Miller, E.F., Murray, J.H., 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Can. J. Fish. Aquat. Sci. 68, 1705–1716. https://doi.org/10.1139/f2011-090

Foster, M.S., Reed, D.C., Carr, M.H., Dayton, P.K., Malone, D.P., Pearse, J.S., Rogers-Bennett, L., 2013. Kelp Forests in California. Smithson. Contrib. Mar. Sci. 39, 115–132.

Free, C.M., Mangin, T., Molinos, J.G., Ojea, E., Burden, M., Costello, C., Gaines, S.D., 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PLoS One 15, 1–21. https://doi.org/10.1371/journal.pone.0224347

Gaines, S.D., Costello, C., Owashi, B., Mangin, T., Bone, J., Molinos, J.G., Burden, M., Dennis, H., Halpern, B.S., Kappel, C. V., Kleisner, K.M., Ovando, D., 2018. Improved fisheries management could offset many negative effects of climate change. Sci. Adv. 4, 1–8. https://doi.org/10.1126/sciadv.aao1378

Ganster, P., 2009. Sustainable Development and the U.S.-Mexico Border Region. Public Adm. Rev. 69, 153–155. https://doi.org/10.1111/j.1540-6210.2008.01957.x

Guenther, C., Lenihan, H., Grant, L., 2012. Trophic cascades induced by lobster fishing are not ubiquitous in Southern California kelp forests.

Guerra, A.S., Madigan, D.J., Love, M.S., Mccauley, D.J., 2017. The worth of giants: The consumptive and non-consumptive use value of the giant sea bass (Stereolepis gigas). Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 1–9. https://doi.org/10.1002/aqc.2837

Hamilton, S.L., Caselle, J.E., 2015. Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forests. Proc. R. Soc. B-BIOLOGICAL Sci. 282. https://doi.org/10.1098/rspb.2014.1817

Hawk, H.A., Allen, L.G., 2014. AGE AND GROWTH OF THE GIANT SEA BASS, STEREOLEPIS GIGAS. Calif. Coop. Ocean. Fish. Investig. REPORTS 55, 128–134.

Hoegh-Guldberg, O., Bruno, J.F., 2010. The Impact of Climate Change on the World's Marine Ecosystems. Science (80-. ). 1523, 1523–1529. https://doi.org/10.1126/science.1189930

Horn, M., Allen, L.G., Lea, R.N., 2006. Biogeography, in: The Ecology of Marine Fishes: California and Adjacent Waters.

Ishimura, G., Herrick, S., Sumaila, U.R., 2013. Fishing games under climate variability: Transboundary management of Pacific sardine in the California Current System. Environ. Econ. Policy Stud. 15, 189–209. https://doi.org/10.1007/s10018-012-0048-0

Kark, S., Levin, N., Grantham, H.S., Possingham, H.P., 2009. Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin. Proc. Natl. Acad. Sci. 106, 15368–15373. https://doi.org/10.1073/pnas.0901001106

Knowlton, N., 2020. Ocean Optimism: Moving Beyond the Obituaries in Marine Conservation. https://doi.org/10.1146/annurev-marine-040220

Lafferty, K.D.K., 2004. Fishing for lobsters indirectly increases epidemics in sea urchins. Ecol. Appl. 14, 1566–1573. https://doi.org/10.1890/03-5088

Lange, G.M., Jiddawi, N., 2009. Economic value of marine ecosystem services in Zanzibar: Implications for marine conservation and sustainable development. Ocean Coast. Manag. 52, 521–532. https://doi.org/10.1016/j.ocecoaman.2009.08.005

Leet, W.S., Dewees, C.M., Klingbeil, R., Larson, E.J., 2001. California's Living Marine Resources: A Status Report, California Department of Fish and Game. University of California Press, Davis, CA.

Levin, N., Tulloch, A.I.T., Gordon, A., Mazor, T., Bunnefeld, N., Kark, S., 2013. Incorporating Socioeconomic and Political Drivers of International Collaboration into Marine Conservation Planning. Bioscience 63, 547–563. https://doi.org/10.1525/bio.2013.63.7.8

López-Hoffman, L., Varady, R.G., Flessa, K.W., Balvanera, P., 2010. Ecosystem services across borders: a framework for transboundary conservation policy. Front. Ecol. Environ. 8, 84–91. https://doi.org/10.1890/070216

Love, M.S., Caselle, J.E., Van Buskirk, W., 1998. A severe decline in the commercial passenger fishing vessel rockfish (Sebastes Spp.) catch in the Southern California Bight, 1980-1996. Calif. Coop. Ocean. Fish. Investig. Reports 39, 180–195.

Micheli, F., Saenz-Arroyo, A., Greenley, A., 2012. Evidence that marine reserves enhance resilience to climatic impacts. PLoS One.

Miller, K.A., Munro, G.R., 2004. Climate and cooperation: A new perspective on the management of shared fish stocks. Mar. Resour. Econ. 19, 367–393. https://doi.org/10.1086/mre.19.3.42629440

Murray, S., Hee, T.T., 2019. A rising tide: California's ongoing commitment to monitoring, managing and enforcing its marine protected areas. Ocean Coast. Manag. 182, 104920. https://doi.org/10.1016/j.ocecoaman.2019.104920

Parnell, P. Edward, Dayton, P.K., Fisher, R.A., Loarie, C.C., Darrow, R.D., 2010. Spatial patterns of fishing effort off San Diego: implications for zonal management and ecosystem function. Ecol. Appl. 20, 2203–2222. https://doi.org/10.1890/09-1543.1

Parnell, P. Ed, Miller, E.F., Lennert-Cody, C.E., Dayton, P.K., Carter, M.L., Stebbins, T.D., 2010. The response of giant kelp (Macrocystis pyrifera) in southern California to low-frequency climate forcing. Limnol. Oceanogr. 55, 2686–2702. https://doi.org/10.4319/lo.2010.55.6.2686

Paterson, C.N., Chabot, C.L., Robertson, J.M., Erisman, B., Cota-Nieto, J.J., Allen, L.G., 2015. The genetic diversity and population structure of barred sand bass, Paralabrax nebulifer: A historically important fisheries species off southern and Baja California. Calif. Coop. Ocean. Fish. Investig. Reports 56, 1–13.

Pendleton, L., Rooke, J., 2010. Understanding the Potential Economic Value of SCUBA Diving and Snorkeling.

Pinsky, M.L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., Cheung, W.W.L., 2018. Preparing ocean governance for species on the move. Science (80-. ). 360, 1189–1191. https://doi.org/10.1126/science.aat2360

Pondella, D.J., Gintert, B.E., Cobb, J.R., Allen, L.G., 2005. Biogeography of the nearshore rocky-reef fishes at the southern and Baja California islands. J. Biogeogr. 32, 187–201. https://doi.org/10.1111/j.1365-2699.2004.01180.x

Ramirez-Valdez, A., Dominguez-Guerrero, I., Palacios-Salgado, D., Villaseñor-Derbez, J., Cota-Nieto, J., Correa-Sandoval, F., Reyes-Bonilla, H., Hinojosa-Arango, G., Hernandez-Velasco, A., Aburto-Oropeza, O., 2015. The nearshore fishes of the Cedros archipelago (North-Eastern Pacific) and their biogeographic affinities. CalCOFI Reports 56, 143–167.

Reed, D.C., Rassweiler, A., Arkema, K.K., Reed, C., 2015. Biomass Rather than Growth Rate Determines Variation in Net Primary Production by Giant Kelp Published by : Ecological Society of America BIOMASS RATHER THAN GROWTH RATE DETERMINES VARIATION IN NET PRIMARY PRODUCTION BY GIANT KELP 89, 2493–2505.

Schiel, D., Foster, M., 2015. The Biology and Ecology of Giant Kelp Forests.

Schroeder, D.M., Love, M.S., 2002. Recreational fishing and marine fish populations in california 43, 182–190.

Selkoe, K., Vogel, A., Gaines, S., 2007. Effects of ephemeral circulation on recruitment and connectivity of nearshore fish populations spanning Southern and Baja California. … Ecol. Ser. … 351, 209–220.

Selkoe, K.A., Watson, J.R., White, C., Ben Horin, T., Iacchei, M., Mitarai, S., Siegel, D.A., Gaines, S.D., Toonen, R.J., 2010. Taking the chaos out of genetic patchiness: seascape genetics reveals ecological and oceanographic drivers of genetic patterns in three temperate reef species. Mol. Ecol. 19, 3708–3726. https://doi.org/10.1111/j.1365-294X.2010.04658.x

Shaw, M.R., Pendleton, L., Cameron, D.R., Morris, B., Bachelet, D., Klausmeyer, K., Mackenzie, J., Conklin, D.R., Bratman, G.N., Lenihan, J., Haunreiter, E., Daly, C., Roehrdanz, P.R., 2011. The impact of climate change on California's ecosystem services 109, 465–484.

Sosa-Nishizaki, O., Guerrero-Ávila, C., García-Rodríguez, E., Rodriguez Medrano, M.C., Saldaña-Ruiz, L.E., Mejía-Mercado, B.E., Dominguez-Reza, R.H., Castro-Velasco, F., 2013. Caracterización de la pesca deportiva en Baja California. Ensenada.

Tegner, M.J., Dayton, P.K., 2000. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

Tegner, M.J.M., Dayton, P.K.P., 1981. Population Structure, Recruitment and Mortality of Two Sea Urchins (Strongylocentrotus franciscanus and S. purpuratus) in a Kelp Forest. Mar. Ecol. Prog. Ser. 5, 255–268. https://doi.org/10.3354/meps005255

Tegner, M.J.M., Dayton, P.P.K., 1987. El Niño Effects on Southern California Kelp Forest Communities. Adv. Ecol. Res. 17, 243–279.

Tegner, M.J.M.J., Dayton, P.K.P.K., 2000. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

Torres-Moye, G., Edwards, M.S., Gabriela Montano-Moctezuma, C., 2013. Benthic community structure in kelp forests from the Southern California Bight. CIENCIAS Mar. 39, 239–252. https://doi.org/10.7773/cm.v39i3.2250

Vásquez, J., Zuñiga, S., Tala, F., Vasquez, J.A., Zuniga, S., Tala, F., Piaget, N., Rodriguez, D.C., Alonso Vega, J.M., Vásquez, J., Zuñiga, S., Tala, F., 2014. Economic valuation of kelp forests in northern Chile: values of goods and services of the ecosystem. J. Appl. … 26, 1081–1088. https://doi.org/10.1007/s10811-013-0173-6

Wilder, M., 2013. Climate Change and U.S.-Mexico Border Communities, in: Garfin, G., Jardine, A., Merideth, R., Black, M., LeRoy, S. (Eds.), Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. pp. 340–384.

Wilmers, C.C., Estes, J.A., Edwards, M., Laidre, K.L., Konar, B., 2012. Do trophic cascades affect the storage and flux of atmospheric carbon? An analysis of sea otters and kelp forests. Front. Ecol. Environ. 10, 409–415. https://doi.org/10.1890/110176

Worm, B., 2017. Marine conservation: How to heal an ocean. Nature. https://doi.org/10.1038/nature21895

# CHAPTER 1:

# The nearshore fishes of the Cedros Archipelago (North-eastern Pacific) and their biogeographic affinities

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# THE NEARSHORE FISHES OF THE CEDROS ARCHIPELAGO (NORTH-EASTERN PACIFIC) AND THEIR BIOGEOGRAPHIC AFFINITIES

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## ABSTRACT

Located in the central region of the west coast of Baja California Peninsula, the Cedros Archipelago consists of five continental islands (Cedros Island, Natividad, San Benito Este, Medio, and Oeste), with Cedros being the largest island in the Mexican Pacific. This archipelago represents the biogeographic transition zone between the temperate and subtropical region and hence, the end of the geographic distribution of a large number of species. Based on field surveys, literature, and scientific collection records, an exhaustive species list of fishes associated with the archipelago and their biogeographic relationships is presented. The checklist includes 269 species belonging to 191 genera, 97 families, 31 orders, and 4 classes. Of the total species, 105 species were recorded in the field, 57 were the result of the literature review, and 218 species of the records were obtained from collections. A total of 14 biogeographic affinities are presented, where 51% of the species have warm-temperate or cold-temperate affinity and 37% have tropical-subtropical affinity. This work highlights the fish diversity present in a transition zone within the temperate and subtropical marine areas of the Northeastern Pacific. More importantly, it reveals a biogeographic region where a great number of species converge, and may be related with the evolutionary history of different taxa and the geological history of the region.

## INTRODUCTION

The Cedros Archipelago (CEA) includes five continental islands, and is located 10 km off the coast in the east-central region of the Baja California Peninsula (fig. 1). Cedros is the largest island in the Mexican Pacific, and along with San Benito Oeste, Medio, Este, and Natividad Island, represent a land territory of 360.7 km$^2$. The polygon formed between all of these islands accounts for a marine region of 3,928.9 km$^2$.

The CEA forms a group of northwestward-trending islands that are considered an extension of the Vizcaino Desert; therefore a subregion of the Sonoran Desert (Oberbauer 1985). The area was separated from the coast of Baja California by a submersion process in the last glacial period (Busby-Spera 1988), resulting in a 200 m deep channel called the Kellet Channel. The archipelago has a complex geologic history, beginning with rock material accumulated in a deep trough in the late Jurassic period, forming the Jurassic Grand Canyon. During the Cretaceous, the formations were folded, faulted, and overlaid by marine deposits. Finally, uplift occurred as recently as the late Pleistocene (Oberbauer 1985; Busby-Spera 1988).

The Pacific islands of the Baja California Peninsula can be considered as among the least degraded ecosystems in continental islands (Littler 1980; Richards 2000; Pondella et al. 2005; Aguirre-Munoz et al. 2008), however unlike their terrestrial biodiversity (Huey 1942; Oberbauer 1985; Mellink 1993; Aguirre-Munoz et al. 2008), the marine diversity has been poorly documented. This contrasts with ecological interest on the central region of the Baja California Peninsula, which represents a transition zone between the San Diegan and the Cortez biogeographic provinces (sensu Horn et al. 2006; Ruiz-Campos et al. 2010). South of the CEA the cold waters from the California Current system converge

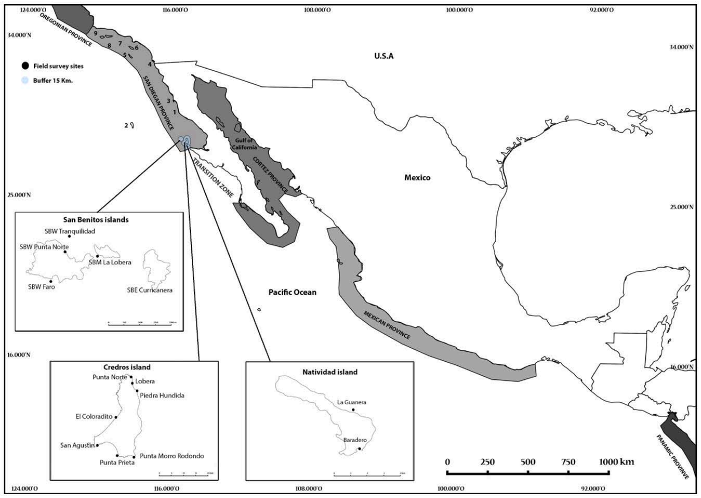

Figure 1. Locations of field surveys at the Cedros Archipelago, México

with the subtropical current system from the south, West Mexican Current (Hubbs 1960; Hickey 1979; Kessler 2006; Taylor et al. 2007), and recently documented intricate eddy motions of ocean water masses in the region contribute to the complexity of the coastal upwelling regime (Miller et al. 1999).

To the north of the CEA, temperate species associated with rocky reefs and kelp forests begin to be dominant until Point Conception, California (Horn et al. 2006). To the south of the CEA, species associated with the tropical Cortez and Mexican provinces begin to appear, mainly associated with mangrove ecosystems in estuaries and bays located in Bahía Magdalena (24°47.6'N, 112°18.2'W). While some species associated with the San Diegan faunistic province can be found as far south as Bahía Magdalena, the transition begins sharply at Punta Eugenia (27°50.7'N, 115°4.84'W), a major mainland landmark in front of the archipelago. Kelp forests do not persist farther south than Punta Eugenia and tropical marine species become more common (Taylor et al. 2007).

The CEA region has been historically relevant for extractive purposes, as archaeological investigations have documented an intensive pre-Hispanic use of marine resources (Des Lauriers 2010), and currently there are fisheries that target on spiny lobster (*Panulirus interruptus*; Randall 1840), green abalone (*Haliotis fulgens*; Philippi 1854), and pink abalone (*H. corrugata*; Gray 1828). Although the finfish fishery has less relevance, some taxa are of artisanal importance (e.g., *Paralabrax nebulifer* [Girard 1854]; *P. clathratus* [Girard 1854]; *Semicossyphus pulcher* [Ayres 1854]; and *Seriola lalandi* [Valenciennes 1833; Rodriguez-Valenica et. al 2004]).

Despite the ecological and economical importance of this region, there is scarce information about the species that inhabit it. In fact, most published species lists of marine groups contain only information from occasional visits or literature reviews (e.g., Hubbs 1960; Miller and Lea 1972; Love et al. 2005). The few studies that have specifically targeted any of the islands of the CEA are focused on particular fish families (Clinidae: Stepien and Rosenblatt 1991), species (*Sardinops* spp.: Felix-Uraga et al. 1996; Quiñonez-Velazquez et al. 2002) or habitats (reef fishes: Pondella et al. 2005; intertidal fishes: Carpizo-Ituarte et al. 2012).

Baseline studies for the CEA are a priority because the region has begun to show signs of environmental decay related to anthropogenic impacts. Among them the overexploitation of the fishing resources, overpopulation of Cedros Island, and the Mitsubishi/Mexican government-owned salt-transshipment facility, which is a source of introduction for exotic species (Mellink 1993; Des Lauriers 2009; Aguilar-Rosas et al. 2011). The lack of a detailed fish checklist hinders the efforts of decision-makers, who require comprehensive baseline data to set adequate protocols for monitoring temporal changes in community composition caused either by anthropogenic or natural forces (Reyes-Bonilla et al. 2010). Furthermore, without a thorough inventory of fish species, any biogeographic analysis of the CEA will be limited in its relevance and outcomes.

The main objective of this work is to provide the first comprehensive, systematic checklist of marine ichthyofauna of the CEA. We performed an overview of the composition of fish community and an analysis of zoo-

TABLE 1

**Study sites and habitat in the Cedros Archipelago.**
***I=Intertidal, S=Subtidal; **T=Tidepools, K=Kelp forest, R=Rocky reefs, S=Soft bottom.**

| | Site | Coordinates | Date | Sampled zone* | Habitat** | Temp C |
|---|---|---|---|---|---|---|
| Cedros Island | Punta Norte | 28°21’48.7 N, 115°11’50.7 W | 17-May-12 | I, S | T, K | 14 |
| | Lobera | 28°20’12.1 N, 115°11’43.9 W | 18-May-12 | S | K, R | 14 |
| | San Agustin | 28°4’48.9 N, 115°20’27.3 W | 19-May-12 | I, S | T, K | 14 |
| | El Coloradito | 28°11’54.5 N, 115°15’45.7 W | I | T | | |
| | Punta Prieta | 28°2’14.6 N, 115°15’11.9 W | I | T | | |
| | Punta Morro Redondo | 28°1’56.7 N, 115°11’18.1 W | I | T | | |
| | Piedra Garropa | 28°18’17.5 N, 115°10’19.1 W | 18-May-12 | S | S, R | 14 |
| San Benito | SBE Curricanera | 28°17‘38.5 N - 115°32‘28.1 W | 20-May-12 | I, S | T, K | 15 |
| | SBE Tranquilidad | 28°19.0‘ N - 115°35.0‘ W | 22-May-12 | I, S | T, K | 14 |
| | SBM La Lobera | 28°18‘25 N - 115°34‘11 W | 21-May-12 | S | T, K, R | 16 |
| | SBW Punta Norte | 28°18’29.6 N, 115°35’9.5 W | 22-May-12 | I | T | |
| | SBW Faro | 28°17‘40.7 N - 115°35‘31.1 W | 21-May-12 | S | R | 15 |
| Natividad | Baradero | 27°52‘31.4 N - 115°10‘16.8 W | | I, S | T, K | 15 |
| | La Guanera | 27°51‘5.8 N - 115°10‘2.6 W | | S | T, K | 15 |

geographic affinity of the species using field surveys, fish collection records, and a full literature review. The results highlight that the relatively high local fish diversity is a result of physical and biological factors determining the transition between warm temperate and subtropical communities in the northeastern Pacific.

## MATERIALS AND METHODS

The Cedros Archipelago (CEA) is composed of five islands. Cedros is the dominant topographic feature of a 400 km long submerged ridge, with a maximum height of 1,204 m, encompassing an area of 348.2 km$^2$ and laying approximately 22 km from the nearest point on the central coast of the Baja California Peninsula (fig. 1). San Benito Archipelago has three small islands situated 31.5 km west of Cedros, encompassing an area of 6 km$^2$ and with a highest altitude of 212 m. Finally, Natividad is located 7.5 km west of Punta Eugenia and measures 6 km in length and 2.5 km at its maximum width, accounting an area of 7.28 km$^2$.

In order to compile the fish checklist of the CEA, we followed three steps. First, we gathered information from electronic and in-house scientific collections from institutions in México, the United States, and Canada, encompassing records between 1934 and 2001. In the case of museum data, we reviewed records from thirty collections, either electronically or by direct visits, obtaining records of the following eleven institutions: Universidad Autónoma de Baja California (UABC; Ensenada); Centro Interdisciplinario de Ciencias Marinas (CICIMAR; La Paz); Instituto de Biología de la Universidad Nacional Autónoma de México (México, DF); Scripps Institution of Oceanography (La Jolla); Los Angeles County Natural History Museum (Los Angeles); California Academy of Sciences (San Francisco); National Museum of Natural History, Smithsonian Institution (Washington, DC); American Museum of Natural History (New York); University of Kansas Natural History Museum (Kansas City); University of Florida (Gainesville); and Canadian Museum of Nature Fish Collection (Dartmouth).

Second, we conducted an extensive literature review of the species reported in peer reviewed articles and technical reports from libraries at UABC (Ensenada, México), CICIMAR (La Paz, México), Centro de Investigaciones Biológicas del Noroeste (La Paz, México), Centro de Investigación Científica y de Educación Superior de Ensenada (Ensenada, México), and Scripps Institution of Oceanography (La Jolla, CA).

Finally, we conducted field surveys around the islands between 2010 and 2012 (table 1). Field surveys included intertidal and subtidal samplings. Intertidal fishes were sampled during eight sampling campaigns, carried out between February 2010 to April 2012 in the rocky tidepools of five sites at Cedros Island, two at San Benito, and two at Natividad (fig. 1, table 1). Tidepools were sprayed using manual aspersion pumps containing a solution of 10% eugenol (clove oil) dissolved in ethanol. After 10 minutes, the tidepools were thoroughly checked using dip and hand nets (Ruiz-Campos et al. 2010).

Subtidal fishes were sampled in May 2012 through underwater visual censuses performed by trained scuba divers. Using 30 × 2 m belt transects, we dove at three different depths (10, 15, and 20 m) and three main habitats (kelp forest, rocky reef, and soft-bottom). We carried out a total of 66 transects in four sites at Cedros, four sites at San Benito and two at Natividad. The total surveyed area with visual censuses was 3,960 m$^2$. Subtidal species were also recorded using the roving dive technique and underwater photography. Voucher specimens of all recorded species in tidepools were kept in the Fish Collection at UABC, while most of the species recorded in the subtidal had in situ photographs taken.

In order to establish which records would be considered as valid for purposes of the study, in a geographical information system (QGIS 2.8) we traced a buffer area of 15 km around the archipelago. The records with coordinates inside the buffer area were considered part of the checklist, independently of the collection method or year of collection.

The taxonomic identification was performed using descriptions by Miller and Lea (1972), Fischer et al. (1995), and Robertson and Allen (2015). A specialized bibliography was also used for some groups (e.g., clingfishes [Briggs 1955]; gobies [Hoese and Reader 2001]; labrisomid blennies [Hubbs 1953]; rays [Castro-Aguirre and Espinoza-Pérez 1996]; sharks [Espinosa-Pérez et al. 2004]; tube blennies [Stephens 1963 and Stephens et al. 1996]). The final checklist follows a systematics order according to Eschmeyer (2015), with modifications by Wiley and Johnson (2010). Genera and species names are presented alphabetically. To eliminate synonyms and generate a systematic list consisting only of valid names, each taxonomic name was corroborated in the Catalog of Fishes of the California Academy of Sciences (Eschmeyer 2015) and common names in Page et al. (2013).

The biogeographic analysis followed three approaches.

1) We created a species presence/absence matrix using the species recorded in our subtidal field surveys at Cedros, San Benito and Natividad Islands, and field records from eight Northeastern Pacific islands gathered from peer review journals (Guadalupe Island, México [Reyes-Bonilla et al. 2010]; San Martin and North Coronado from México; and San Clemente, Santa Catalina, Santa Cruz, Santa Barbara, and San Nicolas from USA [Pondella et al. 2005]). Then, we performed a non-metric multidimensional scaling analysis (nMDS) (Kruskal & Wish, 1978) using the unweighted paired group method and arithmetic averages (UPGMA), based on a Bray-Curtis similarity matrix. SIMPER analysis was used to determine which species contributed with the largest dissimilarity patterns, using the statistical package PRIMER 6.1 (Primer-E Ltd: Plymouth; Clarke and Gorley 2006).
2) Species distributions were plotted using the available information for northern and southern endpoints following Love et al. (2005), and Robertson and Allen (2015). If a species had not been reported at CEA but was observed during field surveys, endpoints were updated with such information. We developed a MATLAB routine to generate latitudinal distribution for the 262 species with known distribution. We defined species with wide distribution those that have a full geographic range covering at least 60 degrees in latitude and which occurred beyond 30 degrees of latitude in both hemispheres.
3) Finally, we assessed the regionalization of the fish species recorded at CEA. The zoogeographic affinity of the ichthyofauna was achieved following Horn et al. (2006) for the North Pacific region, and Hastings (2000) for the Tropical Eastern Pacific, with modifications from Robertson and Cramer (2009). Considering their distribution range, the species were grouped into eight biogeographic provinces from the Eastern Pacific (Briggs 1974), one realm (North Pacific), and three distribution patterns (AmphiAmerican, Circumtropical, and Circumglobal).

## RESULTS

The field surveys, museum records, and literature review, taken together helped to construct a list of 269 species of marine fishes of the CEA, from 191 genera, 97 families, 31 orders, and 4 classes (table 2). Perciformes was the most commonly represented order, with 33 families and 106 species in total. Almost half of the families (48) are represented by a single species. The most speciose families were Sebastidae (22 spp.), Myctophidae (16 spp.), and Embiotocidae (10 spp.). The genera with the highest number of species were *Sebastes* (22 spp.) and loosely followed by *Citharichthys* (5 spp.), and *Apogon*, *Halichoeres*, *Paralabrax*, *Icelinus*, *Lepophidium*, and *Pleuronichthys* with 4 species each.

The nMDS ordination plot based on presence/absence data clearly shows a separation of the CEA from the other eight northern islands, located in the California Current system (fig. 2). The fish assemblages from Cedros, Natividad, and San Benito are tightly grouped, indicating high similarities (>50%), while the Channel Islands, North Coronado, and Guadalupe Islands constitute a more spread group with equivalent similarity between fish assemblages (<50%), and San Martin island is separated from the rest.

According to the geographic distribution, 135 species have a temperate affinity (warm-temperate to cold-temperate) and 92 species have a tropical affinity (tropical-subtropical). A third group of 35 species are widely distributed in tropical and subtropical seas, and a geographic distribution was not assigned to seven taxa that were not identified to specific level (fig. 3).

A total of 170 species comes from a single source (field record, scientific collections and literature review) and 100 species came from multiple sources (table 2). Considering all records, 105 species were seen or collected in the field, 57 taxa were cited in the literature review and 218 species had specimens from the CEA housed in scientific collections. Based on our field records, 90 species were recorded in the subtidal (soft bottom [9 spp.]; kelp forest and rocky reefs [84 spp.],

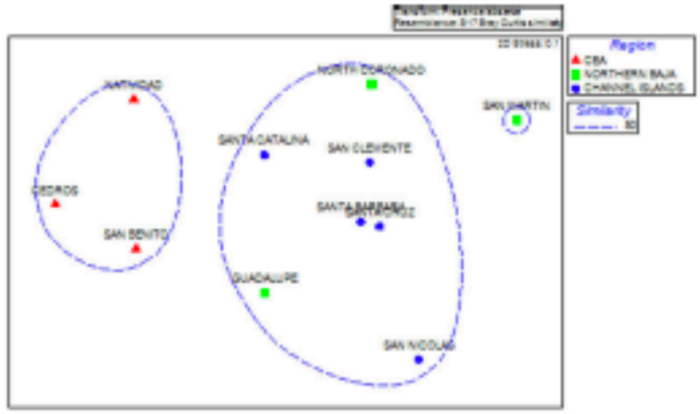

Figure 2. Non-metric Multidimensional Scaling analysis (nMDS) for fish species recorded in the subtidal field surveys at Cedros, Natividad and San Benito, and eight islands in the Pacific coast of Baja California and California [data from Pondella et al. (2005), Reyes-Bonilla et al. (2010) and present study].

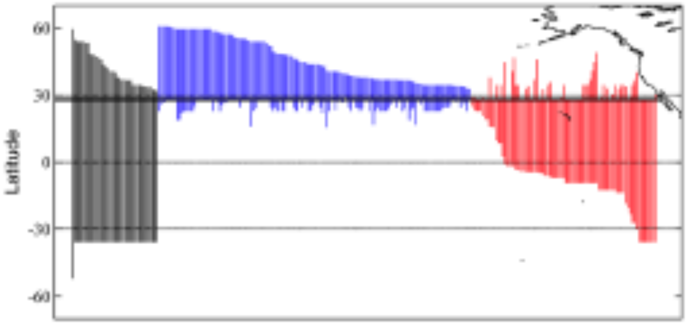

Figure 3. Distribution ranges (bars) in the eastern Pacific of 282 species included in Table 1. Black lines: species widely distributed in the EP surpassing the 30 degrees Latitude in both hemispheres. Blue lines: species with temperate affinity. Red lines: fishes with tropical-subtropical affinity. Black line: Latitude in where CEA archipelago is located.

3 species were present in both habitats). The intertidal fieldwork contributed with 24 species to the checklist.

Analyzing separately the species richness for each of the islands, Cedros had more than twice the number of taxa as San Benito (224 and 107, respectively) and four times that for Natividad Island (63 spp.). The differences are largely reduced when considering only the field surveys; in Cedros 78 species were seen or collected, 54 and 56 species at San Benito and Natividad, respectively.

The CEA represents the limit of geographical distribution for 104 species; 38% of the total species checklist. For 35 species the archipelago is the northern limit, and for 47 species it is the southernmost point of distribution (fig. 3). From the listing, we have range extensions for 19 species. For 9 species, this represents the northernmost documented record, and for 10 species the southernmost record (table 3).

According to the geographic distribution information of all the species, we found 14 distribution patterns; these included one or more biogeographic provinces (fig. 4). The distribution ranges of 95% of the species comprise two or more biogeographic provinces. The best-represented distribution in number of species was the Oregonian-San Diegan, with 46 species. The distribution pattern Aleutian-San Diegan was represented with 25 species.

The presence of 10 endemic species to the San Diegan province was recorded (fig. 4), including: the lined clingfish (*Gobiesox eugrammus*), the yellowchin sculpin (*Icelinus quadriseriatus*), the southern clingfish (*Rimicola dimorpha*), the Guadalupe blenny (*Starksia guadalupae*) the chocolate pipefish (*Syngnathus euchrous*), the tripefin poacher (*Xeneretmus ritteri*), the island kelpfish (*Alloclinus holderi*), the California moray (*Gymnothorax mordax*), the

TABLE 2

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MYXINI** | | | | | | | | | | | |
| | **MYXINIFORMES** | | | | | | | | | | |
| | | MYXINIDAE | | | | | | | | | |
| | | | *Eptatretus deani* (Evermann & Goldsborough 1907) | Black hagfish | 2 | 2 | | LACM, SIO | | Southern limit | AL-SD |
| | | | *Eptatretus mcconnaugheyi* (Wisner & McMillan 1990) | Shorthead hagfish | 3 | 3 | | | | Southern limit | SD-CZ |
| | | | *Eptatretus stoutii* (Lockington 1878) | Pacific hagfish | 2 | 2 | | LACM, SIO | | | OR-SD |
| **CHONDRICHTHYES** | | | | | | | | | | | |
| | **HEXANCHIFORMES** | | | | | | | | | | |
| | | HEXANCHIDAE | | | | | | | | | |
| | | | *Notorynchus cepedianus* (Péron 1807) | Broadnose sevengill shark | | | 1 | | S | | CG |
| | **HETERODONTIFORMES** | | | | | | | | | | |
| | | HETERODONTIDAE | | | | | | | | | |
| | | | *Heterodontus francisci* (Girard 1855) | Horn shark | 1, 2 | 1 | 1 | CICIMAR, LACM | S | | OR-CZ |
| | | | *Heterodontus mexicanus* (Taylor & Castro-Aguirre 1972) | Mexican horn shark | 1, 3 | 3 | 1 | | S | | MX-PA |
| | **LAMNIFORMES** | | | | | | | | | | |
| | | LAMNIDAE | | | | | | | | | |
| | | | *Isurus oxyrinchus* (Rafinesque 1810) | Shortfin mako | | | 1 | | S | | CG |
| | **CARCHARINIFORMES** | | | | | | | | | | |
| | | SCYLIORHINIDAE | | | | | | | | | |
| | | | *Cephaloscyllium ventriosum* (Garman 1880) | Swell shark | | 2 | | SIO | | | OR-CH |
| | | TRIAKIDAE | | | | | | | | | |
| | | | *Galeorhinus galeus* (Linnaeus 1758) | Tope | | 2 | | IGUNAM, SIO | | | CG |
| | | | *Mustelus californicus* (Gill 1864) | Gray smoothhound | 2 | | | CICIMAR | | | OR-CZ |
| | | | *Mustelus lunulatus* (Jordan & Gilbert 1882) | Sicklefin smoothhound | | 2 | | SIO | | | SD-CH |
| | | | *Triakis semifasciata* (Girard 1855) | Leopard shark | | 2 | | CICIMAR, SIO | | | OR-MX |
| | | CARCHARHINIDAE | | | | | | | | | |
| | | | *Carcharhinus brachyurus* (Günther 1870) | Narrowtooth shark | | 2 | | IGUNAM, SIO | | | CG |
| | | SPHYRNIDAE | | | | | | | | | |
| | | | *Sphyrna zygaena* (Linnaeus 1758) | Smooth hammerhead | 3 | | | | | | CT |
| | | | *Sphyrna* sp. | | | | 1 | | S | | |
| | **SQUATINIFORMES** | | | | | | | | | | |
| | | SQUATINIDAE | | | | | | | | | |
| | | | *Squatina californica* (Ayres 1859) | Pacific angelshark | 1 | | 1 | | S | | EP |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **OSMERIFORMES** | | | | | | | | | | |
| | | ARGENTINIDAE | | | | | | | | | |
| | | | *Argentina sialis* (Gilbert 1890) | Pacific argentine | 2 | 2 | | CICIMAR, IBUNAM, LACM, SIO | | | OR-SD |
| | | MICROSTOMATIDAE | | | | | | | | | |
| | | | *Nansenia crassa* (Lavenberg 1965) | Stout argentine | 2 | | | CICIMAR | | Southern limit | OR-SD |
| | | BATHYLAGIDAE | | | | | | | | | |
| | | | *Bathylagoides wesethi* (Bolin 1938) | Snubnose blacksmelt | 2 | | | CICIMAR | | | OR-SD |
| | | | *Leuroglossus stilbius* (Gilbert 1890) | California smoothtongue | 2 | | | CICIMAR | | | OR-PA |
| | **STOMIIFORMES** | | | | | | | | | | |
| | | GONOSTOMATIDAE | | | | | | | | | |
| | | | *Cyclothone acclinidens* (Garman 1899) | Benttooth bristlemouth | 2 | | | CICIMAR | | | CG |
| | | | *Cyclothone signata* (Garman 1899) | Showy bristlemouth | 2 | | | CICIMAR | | | EP |
| | | | *Diplophos taenia* (Günther 1873) | Pacific portholefish | 2 | | | CICIMAR | | | CG |
| | | STERNOPTYCHIDAE | | | | | | | | | |
| | | | *Argyropelecus sladeni* (Regan 1908) | Sladen's hatchet fish | 2 | | | CICIMAR | | | CG |
| | | PHOSICHTHYIDAE | | | | | | | | | |
| | | | *Ichthyococcus irregularis* (Rechnitzer & Böhlke 1958) | Bulldog lightfish | 2 | | | CICIMAR | | | NEP |
| | | | *Vinciguerria lucetia* (Garman 1899) | Panama lightfish | 2 | | | IBUNAM, CICIMAR | | | OR-CH |
| | | STOMIIDAE | | | | | | | | | |
| | | | *Idiacanthus antrostomus* (Gilbert 1890) | Pacific blackdragon | 2 | | | CICIMAR | | | TEP |
| | | | *Stomias atriventer* (Garman 1899) | Blackbelly dragonfish | 2 | | | CICIMAR | | Northern limit | SD-CH |
| | **AULOPIFORMES** | | | | | | | | | | |
| | | SCOPELARCHIDAE | | | | | | | | | |
| | | | *Scopelarchus guentheri* (Alcock 1896) | Staring pearleye | 2 | | | CICIMAR | | | CT |
| | | | *Scopelarchoides nicholsi* (Parr 1929) | Pearleye | 3 | | | | | Northern limit | SD-CH |
| | | SYNODONTIDAE | | | | | | | | | |
| | | | *Synodus lacertinus* (Gilbert 1890) | Calico lizardfish | 3 | | | | | | SD-CH-POI |
| | | | *Synodus lucioceps* (Ayres 1855) | California lizardfish | 2 | 2 | | IBUNAM, CICIMAR, LACM, SIO | | Southern limit | OR-CZ |
| | | PARALEPIDIDAE | | | | | | | | | |
| | | | *Arctozenus risso* (Bonaparte 1840) | White barracudina | 2 | | | CICIMAR | | Southern limit | CG |
| | | | *Lestidiops ringens* (Jordan & Gilbert 1880) | Slender barracudina | 2 | | | CICIMAR, LACM | | Southern limit | OR-SD |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **MYCTOPHIFORMES** | | | | | | | | | | |
| | | MYCTOPHIDAE | | | | | | | | | |
| | | | *Ceratoscopelus townsendi* (Eigenmann & Eigenmann 1889) | Dogtooth lampfish | 2 | | | CICIMAR | | | CG |
| | | | *Diogenichthys atlanticus* (Tåning 1928) | Longfin lanternfish | 2 | | | CICIMAR | | | CG |
| | | | *Diogenichthys laternatus* (Garman 1899) | Diogenes lanternfish | 2 | | | CICIMAR | | | SD-CH |
| | | | *Electrona risso* (Cocco 1829) | Electric lanternfish | 2 | | | CICIMAR | | | CG |
| | | | *Gonichthys tenuiculus* (Garman 1899) | Slendertail lanternfish | 2 | | | CICIMAR | | | SD-CH |
| | | | *Hygophum atratum* (Garman 1899) | Thickhead flashlightfish | 2 | | | CICIMAR | | | CZ |
| | | | *Hygophum reinhardtii* (Lütken 1892) | Reinhardt's lanternfish | 2 | | | CICIMAR | | | AA |
| | | | *Lampadena urophaos* (Paxton 1963) | Sunbeam lampfish | 2, 3 | | | CICIMAR | | | AA |
| | | | *Loweina rara* (Lütken 1892) | Laura's lanternfish | 2 | | | CICIMAR | | | CG |
| | | | *Myctophum nitidulum* (Garman 1899) | Pearly lanternfish | 2 | | | CICIMAR | | | CG |
| | | | *Nannobrachium idostigma* (Parr 1931) | Lanternfish | 2 | | | CICIMAR | | Range extension North | TEP |
| | | | *Nannobrachium ritteri* (Gilbert 1915) | Broadfin lampfish | 2 | | | CICIMAR | | Southern limit | NEP |
| | | | *Notolychnus valdiviae* (Brauer 1904) | Topside lampfish | 2 | | | CICIMAR | | | CT |
| | | | *Protomyctophum crockeri* (Bolin 1939) | California flashlightfish | 2 | | | CICIMAR | | | NP |
| | | | *Symbolophorus californiensis* (Eigenmann & Eigenmann 1889) | Bigfin lanternfish | 2, 3 | | | CICIMAR | | Southern limit | NP |
| | | | *Triphoturus mexicanus* (Gilbert 1890) | Mexican lampfish | 2 | | | CICIMAR | | | AL-MX |
| | **LAMPRIFORMES** | | | | | | | | | | |
| | | TRACHIPTERIDAE | | | | | | | | | |
| | | | *Zu cristatus* (Bonelli 1820) | Scalloped ribbonfish | 2 | | | SIO | | | CG |
| | **GADIFORMES** | | | | | | | | | | |
| | | MORIDAE | | | | | | | | | |
| | | | *Physiculus rastrelliger* (Gilbert 1890) | Hundred-fathom codling | 2 | | | SIO | | | OR-PA |
| | | MERLUCCIIDAE | | | | | | | | | |
| | | | *Merluccius productus* (Ayres 1855) | Pacific hake | 2 | | | CICIMAR, SIO | | | AL-MX |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **OPHIDIIFORMES** | | | | | | | | | | |
| | | OPHIDIIDAE | | | | | | | | | |
| | | | *Chilara taylori* (Girard 1858) | Spotted cusk-eel | 2 | | | LACM, SIO | | | OR-PA |
| | | | *Lepophidium negropinna* (Hildebrand & Barton 1949) | Specklefin cusk-eel | 2 | | | CICIMAR, SIO | | Northern limit | TEP |
| | | | *Lepophidium prorates* (Jordan & Bollman 1890) | Prowspine cusk-eel | 2 | | | LACM | | Range extension North | TEP |
| | | | *Lepophidium stigmatistium* (Gilbert 1890) | Mexican cusk-eel | 3 | | | | | Northern limit | SD-CZ |
| | | | *Lepophidium* sp. | | 2 | | | LACM | | | |
| | | | *Ophidion galeoides* (Gilbert 1890) | Spotfin cusk-eel | 3 | | | | | Northern limit | SD-PA |
| | | | *Ophidion scrippsae* (Hubbs 1916) | Basketweave cusk-eel | 2 | | | CICIMAR, CAS, LACM, SIO | | | OR-SD |
| | **BATRACHOIDIFORMES** | | | | | | | | | | |
| | | BATRACHOIDIDAE | | | | | | | | | |
| | | | *Porichthys myriaster* (Hubbs & Schultz 1939) | Specklefin midshipman | 2 | | | CICIMAR, SIO | | | OR-PA |
| | | | *Porichthys notatus* (Girard 1854) | Plainfin midshipman | 2 | | | CAS, IBUNAM, LACM, SIO | | | OR-SD |
| | **GOBIESOCIFORMES** | | | | | | | | | | |
| | | GOBIESOCIDAE | | | | | | | | | |
| | | | *Gobiesox eugrammus* (Briggs 1955) | Lined clingfish | | 2 | | SIO | | Southern limit | SD |
| | | | *Gobiesox rhessodon* (Smith 1881) | California clingfish | 1, 2 | 1, 2 | 1 | UABC, LACM, SIO | I | | OR-SD |
| | | | *Rimicola dimorpha* (Briggs 1955) | Southern clingfish | | 2 | | SIO | | Southern limit | SD |
| | | | *Rimicola eigenmanni* (Gilbert 1890) | Slender clingfish | 1, 2 | | | UABC, LACM | I | | SD |
| | **ATHERINIFORMES** | | | | | | | | | | |
| | | ATHERINIDAE | | | | | | | | | |
| | | | *Leuresthes tenuis* (Ayres 1860) | California grunion | 1, 2 | | | UABC, SIO | I, S | | OR-SD |
| | | ATHERINOPSIDAE | | | | | | | | | |
| | | | *Atherinops affinis* (Ayres 1860) | Topsmelt | 1, 2 | 1, 2 | 1 | UABC, CAS, LACM, SIO | I, S | | AL-CZ |
| | | | *Atherinopsis californiensis* (Girard 1854) | Jacksmelt | 1, 2 | 2 | | UABC, CAS, LACM, SIO | I | | OR-CZ |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **BELONIFORMES** | | | | | | | | | | |
| | | SCOMBERESOCIDAE | | | | | | | | | |
| | | | *Cololabis saira* (Brevoort 1856) | Pacific saury | 2 | 2 | | CICIMAR, CAS, LACM, SIO | | | NP |
| | | BELONIDAE | | | | | | | | | |
| | | | *Platybelone argalus* (Lesueur 1821) | Keeltail needlefish | | 2 | | SIO | | Range extension North | CT |
| | | | *Strongylura exilis* (Girard 1854) | California needlefish | 2, 3 | | | LACM, SIO | | | OR-CH |
| | | | *Tylosurus crocodilus* (Péron & Lesueur 1821) | Hound needlefish | 1, 2 | | 1 | UABCS | S | Northern limit | CG |
| | | HEMIRAMPHIDAE | | | | | | | | | |
| | | | *Euleptorhamphus viridis* (van Hasselt 1823) | Ribbon halfbeak | 2 | 2 | | SIO | | | TR |
| | | | *Hemiramphus saltator* (Gilbert & Starks 1904) | Longfin halfbeak | 2 | | | LACM | | Range extension North | TEP |
| | | EXOCOETIDAE | | | | | | | | | |
| | | | *Cheilopogon heterurus* (Rafinesque 1810) | Blotchwing flyingfish | 2 | | 2 | CICIMAR, SIO | | | CT |
| | | | *Cheilopogon pinnatibarbatus* (Bennett 1831) | Smallhead flyingfish | 2 | 2 | 2 | CAS, LACM, SIO | | | OR-CZ |
| | | | *Cypselurus* sp. | | 2 | | | LACM | | | |
| | **STEPHANOBERYCIFORMES** | | | | | | | | | | |
| | | MELAMPHAIDAE | | | | | | | | | |
| | | | *Melamphaes lugubris* (Gilbert 1890) | Highsnout melamphid | 2 | | | CICIMAR | | Southern limit | NEP |
| | **BERYCIFORMES** | | | | | | | | | | |
| | | HOLOCENTRIDAE | | | | | | | | | |
| | | | *Myripristis leiognathus* (Valenciennes 1846) | Panamic soldierfish | 1, 2 | | | SIO | S | Northern limit | TEP |
| | **SYNGNATHIFORMES** | | | | | | | | | | |
| | | CENTRISCIDAE | | | | | | | | | |
| | | | *Macroramphosus gracilis* (Lowe 1839) | Slender snipefish | | 2 | | IBUNAM, CICIMAR, LACM, SIO | | | CG |
| | | SYNGNATHIDAE | | | | | | | | | |
| | | | *Syngnathus euchrous* (Fritzsche 1980) | Chocolate pipefish | 2 | | | CAS, SIO | | Southern limit | SD |
| | | | *Syngnathus exilis* (Osburn & Nichols 1916) | Barcheek pipefish | 2, 3 | 2 | | CAS, SIO | | Southern limit | OR-SD |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **SCORPAENIFORMES** | | | | | | | | | | |
| | | SEBASTIDAE | | | | | | | | | |
| | | | *Sebastes atrovirens* (Jordan & Gilbert 1880) | Kelp rockfish | 1, 2 | 1, 2 | | LACM, SIO | S | Southern limit | OR-SD |
| | | | *Sebastes auriculatus* (Girard 1854) | Brown rockfish | 1 | 1 | | | S | | NEP |
| | | | *Sebastes aurora* (Gilbert 1890) | Aurora rockfish | 3 | | | | | Southern limit | NEP |
| | | | *Sebastes carnatus* (Jordan & Gilbert 1880) | Gopher rockfish | | | 2 | LACM | | | OR-SD |
| | | | *Sebastes caurinus* (Richardson 1844) | Copper rockfish | | 1, 2, 3 | | LACM | S | Southern limit | NEP |
| | | | *Sebastes chrysomelas* (Jordan & Gilbert 1881) | Black-and-yellow rockfish | | | 2 | LACM | | | OR-SD |
| | | | *Sebastes diploproa* (Gilbert 1890) | Splitnose rockfish | 2, 3 | | | SIO | | Southern limit | NEP |
| | | | *Sebastes elongatus* (Ayres 1859) | Greenstriped rockfish | 1, 3 | | | | S | Southern limit | NEP |
| | | | *Sebastes flavidus* (Ayres 1862) | Yellowtail rockfish | 1 | | | | S | Range extension South | AL-SD |
| | | | *Sebastes hopkinsi* (Cramer 1895) | Squarespot rockfish | 1 | 1 | | | S | Range extension South | OR-SD |
| | | | *Sebastes lentiginosus* (Chen 1971) | Freckled rockfish | 2 | | | LACM | | Southern limit | OR-SD |
| | | | *Sebastes macdonaldi* (Eigenmann & Beeson 1893) | Mexican rockfish | 2 | | | CICIMAR, LACM | | | SD-CZ |
| | | | *Sebastes melanostomus* (Eigenmann & Eigenmann 1890) | Blackgill rockfish | 3 | | | | | Southern limit | OR-SD |
| | | | *Sebastes miniatus* (Jordan & Gilbert 1880) | Vermilion rockfish | | 1, 2, 3 | | LACM | S | Southern limit | AL-SD |
| | | | *Sebastes paucispinis* (Ayres 1854) | Bocaccio rockfish | 2 | | | SIO | | Range extension South | NEP |
| | | | *Sebastes rosaceus* (Girard 1854) | Rosy rockfish | 2 | | | SIO | | Southern limit | OR-SD |
| | | | *Sebastes saxicola* (Gilbert 1890) | Stripetail rockfish | 2 | | | SIO | | | NEP |
| | | | *Sebastes semicinctus* (Gilbert 1897) | Halfbanded rockfish | 2 | | | SIO | | Range extension South | OR-SD |
| | | | *Sebastes serranoides* (Eigenmann & Eigenmann 1890) | Olive rockfish | | 1, 2, 3 | | SIO | S | Southern limit | OR-SD |
| | | | *Sebastes serriceps* (Jordan & Gilbert 1880) | Treefish | 1, 2, 3 | | | LACM | S | Southern limit | OR-SD |
| | | | *Sebastes* sp. | Rockfish | 1 | 1 | | | S | | |
| | | | *Sebastes umbrosus* (Jordan & Gilbert 1882) | Honeycomb rockfish | | 2 | | LACM | | Southern limit | OR-SD |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **SCORPAENIFORMES (continued)** | | | | | | | | | | |
| | | SCORPAENIDAE | | | | | | | | | |
| | | | *Pontinus vaughani* (Barnhart & Hubbs 1946) | Spotback scorpionfish | 1, 2 | | | SIO | S | Range extension North | CZ-POI |
| | | | *Scorpaena guttata* (Girard 1854) | California scorpionfish | 1, 2 | | | UABC, CICIMAR, LACM, SIO | I, S | | SD-CZ |
| | | | *Scorpaenodes xyris* (Jordan & Gilbert 1882) | Rainbow scorpionfish | 2 | 2 | | LACM, SIO | | | SD-PA-POI |
| | | EPINEPHELIDAE | | | | | | | | | |
| | | | *Mycteroperca rosacea* (Streets 1877) | Leopard grouper | | | 1 | | S | | SD-MX |
| | | TRIGLIDAE | | | | | | | | | |
| | | | *Prionotus ruscarius* (Gilbert & Starks 1904) | Rough searobin | 2 | | | CICIMAR | | Range extension North | SD-CH |
| | | | *Prionotus stephanophrys* (Lockington 1881) | Lumptail searobin | 2 | | | CAS, LACM | | | OR-CH |
| | **PERCIFORMES** | | | | | | | | | | |
| | | POLYPRIONIDAE | | | | | | | | | |
| | | | *Stereolepis gigas* (Ayres 1859) | Giant seabass | | | 1 | | S | | SD-CZ |
| | | SERRANIDAE | | | | | | | | | |
| | | | *Alphestes immaculatus* (Breder 1936) | Pacific mutton hamlet | | 1 | 1 | | | Northern limit | TEP |
| | | | *Epinephelus labriformis* (Jenyns 1840) | Flag cabrilla | 1, 3 | 1, 3 | | | S | | SD-PA-POI |
| | | | *Paralabrax auroguttatus* (Walford 1936) | Goldspotted sand bass | 1, 2, 3 | | | LACM | S | Northern limit | CZ |
| | | | *Paralabrax clathratus* (Girard 1854) | Kelp bass | 1, 2 | 1, 2 | 1, 2 | CICIMAR, LACM, SIO | S | | OR-SD |
| | | | *Paralabrax maculatofasciatus* (Steindachner 1868) | Spotted sand bass | 2 | | | CICIMAR | | | OR-CZ |
| | | | *Paralabrax nebulifer* (Girard 1854) | Barred sand bass | 1, 2 | 1, 2 | 1 | CICIMAR, LACM, SIO | S | | OR-MX |
| | | | *Paranthias colonus* (Valenciennes 1846) | Pacific creolefish | | 2 | 1 | LACM | S | Northern limit | TEP |
| | | | *Pronotogrammus multifasciatus* (Gill 1863) | Threadfin bass | 2 | | | CICIMAR | | | SD-PA-POI |
| | | | *Serranus psittacinus* (Valenciennes 1846) | Barred serrano | 1, 3 | | | | S | Northern limit | TEP |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | APOGONIDAE | | | | | | | | | |
| | | | *Apogon atricaudus* (Jordan & McGregor 1898) | Plain cardinalfish | 2, 3 | | | CICIMAR | | | SD-CZ |
| | | | *Apogon guadalupensis* (Osburn & Nichols 1916) | Guadalupe cardinalfish | | 2 | | LACM, SIO | | | SD-CZ |
| | | | *Apogon pacificus* (Herre 1935) | Pink cardinalfish | | 1, 2, 3 | | SIO | S | | SD-CH-POI |
| | | | *Apogon retrosella* (Gill 1862) | Barspot cardinalfish | 1, 2, 3 | 1, 2, 3 | 1 | LACM, SIO | S | Northern limit | TEP |
| | | MALACANTHIDAE | | | | | | | | | |
| | | | *Caulolatilus princeps* (Jenyns 1840) | Ocean whitefish | 1, 2 | 1, 2 | 1, 2 | LACM, SIO | S | | EP |
| | | CARANGIDAE | | | | | | | | | |
| | | | *Caranx caballus* (Günther 1868) | Green jack | | | 1 | | S | | SD-CH |
| | | | *Chloroscombrus orqueta* (Jordan & Gilbert 1883) | Pacific bumper | 2 | | | CICIMAR | | | SD-CH |
| | | | *Decapterus muroadsi* (Temminck & Schlegel 1844) | Amberstripe scad | 2 | 2 | | LACM | | Northern limit | TR |
| | | | *Seriola lalandi* (Valenciennes 1833) | Yellowtail jack | 1, 2 | 1 | 1, 2 | CICIMAR, LACM, SIO | S | | CT |
| | | | *Trachurus symmetricus* (Ayres 1855) | Pacific jack mackerel | 1 | 1, 2 | | CICIMAR, LACM, SIO | S | | AL-CZ |
| | | | *Uraspis secunda* (Poey 1860) | Whitemouth jack | | 2 | | SIO | | | CG |
| | | CORYPHAENIDAE | | | | | | | | | |
| | | | *Coryphaena hippurus* (Linnaeus 1758) | Dolphinfish | 2 | | 1 | CICIMAR, SIO | S | | CT |
| | | CARISTIIDAE | | | | | | | | | |
| | | | *Caristius macropus* (Bellotti 1903) | Bigmouth manefish | 3 | | | | | Southern limit | NEP |
| | | GERREIDAE | | | | | | | | | |
| | | | *Eucinostomus dowii* (Gill 1863) | Pacific spotfin mojarra | | 2 | | SIO | | | SD-CH |
| | | HAEMULIDAE | | | | | | | | | |
| | | | *Anisotremus davidsonii* (Steindachner 1876) | Sargo | 1, 2 | 1, 2 | 1 | CICIMAR, LACM, SIO | S | | SD-CZ |
| | | | *Anisotremus interruptus* (Gill 1862) | Burrito grunt | 1 | | | | S | Northern limit | TEP |
| | | | *Orthopristis reddingi* (Jordan & Richardson 1895) | Bronzestriped grunt | 2, 3 | | | CAS | | Northern limit | SD-MX |
| | | | *Xenistius californiensis* (Steindachner 1876) | Salema | 1 | 1 | | | S | | OR-PA |

*(continued)*

TABLE 2 (Continued)

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| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | SPARIDAE | | | | | | | | | |
| | | | *Calamus brachysomus* (Lockington 1880) | Pacific porgy | | 2 | 1 | SIO | S | | SD-CH |
| | | SCIAENIDAE | | | | | | | | | |
| | | | *Cheilotrema saturnum* (Girard 1858) | Black croaker | | 2 | | SIO | | | SD-CZ |
| | | | *Genyonemus lineatus* (Ayres 1855) | White croaker | 2 | | | SIO | | | OR-SD |
| | | | *Larimus acclivis* (Jordan & Bristol 1898) | Steeplined drum | 3 | | | | | Northern limit | TEP |
| | | | *Pareques* sp. | Croaker | 1 | 1, 2 | | | S | | |
| | | | *Seriphus politus* (Ayres 1860) | Queenfish | 2 | | | SIO | | | OR-CZ |
| | | | *Umbrina roncador* (Jordan & Gilbert 1882) | Yellowfin croaker | 2 | | | SIO | | | SD-CZ |
| | | KYPHOSIDAE | | | | | | | | | |
| | | | *Girella nigricans* (Ayres 1860) | Opaleye | 1, 2 | 1, 2 | 1, 2 | UABC, LACM, SIO | I, S | | SD-CZ |
| | | | *Kyphosus azurea* (Jenkins & Evermann 1889) | Zebraperch | 1, 2 | | 1, 2 | UABC, CICIMAR | I, S | | OR-CZ |
| | | | *Medialuna californiensis* (Steindachner 1876) | Halfmoon | 1, 2 | 1, 2 | 1, 2 | IBUNAM, CICIMAR, LACM, SIO | S | | AL-CZ |
| | | CHAETODONTIDAE | | | | | | | | | |
| | | | *Chaetodon humeralis* (Günther 1860) | Threebanded butterflyfish | | 2 | | SIO | | Northern limit | SD-CH |
| | | | *Johnrandallia nigrirostris* (Gill 1862) | Barberfish | 1, 3 | 3 | | | S | Northern limit | TEP |
| | | | *Prognathodes falcifer* (Hubbs & Rechnitzer 1958) | Scythe butterflyfish | 2 | 1, 2 | | LACM, SIO | S | | SD-CZ |
| | | MUGILIDAE | | | | | | | | | |
| | | | *Mugil curema* (Valenciennes 1836) | White mulet | | | 1, 2 | UABC | I | | CT |
| | | POMACANTHIDAE | | | | | | | | | |
| | | | *Pomacanthus zonipectus* (Gill 1862) | Cortez angelfish | | 2 | | SIO | | | TEP |

*(continued)*

TABLE 2 (Continued)

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| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | EMBIOTOCIDAE | | | | | | | | | |
| | | | *Brachyistius frenatus* (Gill 1862) | Kelp surfperch | 1, 2 | 1, 2 | 1 | SIO | S | Southern limit | AL-SD |
| | | | *Embiotoca jacksoni* (Agassiz 1853) | Black perch | 1, 2 | 1, 2 | 1, 2 | CICIMAR, SIO | S | | OR-SD |
| | | | *Embiotoca* sp. | | 2 | | | SIO | | | |
| | | | *Hyperprosopon argenteum* (Gibbons 1854) | Walleye surfperch | 2 | | | SIO | | Southern limit | OR-SD |
| | | | *Micrometrus minimus* (Gibbons 1854) | Dwarf perch | 2 | | | SIO | | Southern limit | OR-SD |
| | | | *Phanerodon atripes* (Jordan & Gilbert 1880) | Sharpnose seaperch | 1 | 1, 2 | | SIO | S | Southern limit | OR-SD |
| | | | *Phanerodon furcatus* (Girard 1854) | White seaperch | 1 | 1 | | | S | Range extension South | AL-SD |
| | | | *Rhacochilus toxotes* (Agassiz 1854) | Rubberlip seaperch | 1, 2 | 1, 2 | | LACM, SIO | S | Southern limit | OR-SD |
| | | | *Rhacochilus vacca* (Girard 1855) | Pile perch | 2 | | 1 | LACM | S | Range extension South | NEP |
| | | | *Zalembius rosaceus* (Jordan & Gilbert 1880) | Pink seaperch | 2 | | | CAS, LACM, SIO | | Range extension South | OR-CZ |
| | | POMACENTRIDAE | | | | | | | | | |
| | | | *Abudefduf troschelii* (Gill 1862) | Panamic sergeant major | 1, 2 | 1 | 1 | UABC | I, S | Northern limit | SD-CH-POI |
| | | | *Azurina hirundo* (Jordan & McGregor 1898) | Swallow damselfish | | 2, 3 | | KU, SIO | | | SD-CZ |
| | | | *Chromis alta* (Greenfield & Woods 1980) | Silverstripe chromis | 1, 2 | 1, 2 | | KU, SIO | S | | SD-CH-POI |
| | | | *Chromis atrilobata* (Gill 1862) | Scissortail chromis | 1, 2 | 2 | | SIO | S | Northern limit | TEP |
| | | | *Chromis punctipinnis* (Cooper 1863) | Blacksmith | 1, 2 | 1, 2 | 1, 2 | CICIMAR, KU, LACM, SIO | S | | OR-SD |
| | | | *Hypsypops rubicundus* (Girard 1854) | Garibaldi | 1, 2 | 1, 2 | 1, 2 | UABC, CICIMAR, LACM, SIO | I, S | | SD-CZ |
| | | | *Stegastes flavilatus* (Gill 1862) | Beaubrummel | 1, 3 | | | | S | Northern limit | TEP |
| | | | *Stegastes leucorus* (Gilbert 1892) | Whitetail damselfish | | 1, 2 | | SIO | S | | CZ-MX |
| | | | *Stegastes rectifraenum* (Gill 1862) | Cortez damselfish | | 2 | | LACM, SIO | | | SD-MX |

*(continued)*

TABLE 2 (Continued)

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| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | LABRIDAE | | | | | | | | | |
| | | | *Bodianus diplotaenia* (Gill 1862) | Mexican hogfish | 1, 2, 3 | 2 | | LACM | S | Northern limit | SD-CH-POI |
| | | | *Halichoeres dispilus* (Günther 1864) | Chameleon wrasse | 1 | 1, 2 | | SIO | S | Northern limit | TEP |
| | | | *Halichoeres melanotis* (Gilbert 1890) | Golden wrasse | 3 | 1, 3 | | | S | Northern limit | TEP |
| | | | *Halichoeres notospilus* (Günther 1864) | Banded wrasse | 1, 2 | | 1 | UABC | I, S | Range extension North | TEP |
| | | | *Halichoeres semicinctus* (Ayres 1859) | Rock wrasse | 1, 2 | 1, 2 | 1, 2 | UABC, CICIMAR, CAS, LACM, SIO | I, S | | SD-CZ |
| | | | *Oxyjulis californica* (Günther 1861) | Señorita | 1 | 1, 2 | 1 | SIO | S | | OR-SD |
| | | | *Semicossyphus pulcher* (Ayres 1854) | California sheephead | 1, 2 | 1, 2 | 1, 2 | LACM, SIO | S | | OR-CZ |
| | | | *Thalassoma lucasanum* (Gill 1862) | Cortez rainbow wrasse | 1 | 1 | | | S | Northern limit | TEP |
| | | SCARIDAE | | | | | | | | | |
| | | | *Nicholsina denticulata* (Evermann & Radcliffe 1917) | Loosetooth parrotfish | 1, 3 | 1, 3 | | | S | | SD-PA-POI |
| | | ZOARCIDAE | | | | | | | | | |
| | | | *Lyconema barbatum* (Gilbert 1896) | Bearded eelpout | 2 | 2 | | SIO | | Southern limit | OR-SD |
| | | CHIASMODONTIDAE | | | | | | | | | |
| | | | *Chiasmodon niger* (Johnson 1864) | Black swallower | 2 | | | CICIMAR | | Range extension South | CG |
| | | URANOSCOPIDAE | | | | | | | | | |
| | | | *Kathetostoma averruncus* (Jordan & Bollman 1890) | Smooth stargazer | 2 | 2 | | UF, LACM, SIO | | | SD-CH |
| | | TRIPTERYGIIDAE | | | | | | | | | |
| | | | *Enneanectes carminalis* (Jordan & Gilbert 1882) | Carmine triplefin | | 1, 2 | | LACM | S | Northern limit | TEP |
| | | | *Enneanectes reticulatus* (Allen & Robertson 1991) | Flag triplefin | | 2 | | SIO | | Northern limit | CZ |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | LABRISOMIDAE | | | | | | | | | |
| | | | *Alloclinus holderi* (Lauderbach 1907) | Island kelpfish | 1, 2 | 1, 2 | 1 | UABC, LACM, SIO | S | | SD |
| | | | *Labrisomus multiporosus* (Hubbs 1953) | Porehead blenny | 1, 2 | | 1, 2 | UABC | I | Northern limit | TEP |
| | | | *Labrisomus* sp. | Blenny | | 2 | | SIO | | | |
| | | | *Labrisomus xanti* (Gill 1860) | Largemouth blenny | 1, 2 | | 1 | UABC, LACM | I | Northern limit | TEP |
| | | | *Paraclinus integripinnis* (Smith 1880) | Reef finspot | 1, 2 | 1, 2 | 2 | UABC, LACM, SIO | I | | OR-SD |
| | | | *Starksia guadalupae* (Rosenblatt & Taylor 1971) | Guadalupe blenny | | 2 | | LACM | | | SD |
| | | CLINIDAE | | | | | | | | | |
| | | | *Gibbonsia elegans* (Cooper 1864) | Spotted kelpfish | 1, 2 | 1, 2 | 1, 2 | UABC, LACM, SIO | I | | OR-SD |
| | | | *Gibbonsia montereyensis* (Hubbs 1927) | Crevice kelpfish | 1, 2 | 1, 2 | 1, 2 | UABC, SIO | I | Range extension South | AL-SD |
| | | | *Heterostichus rostratus* (Girard 1854) | Giant kelpfish | 1, 2 | 1, 2 | 1, 2 | UABC, CAS, LACM, SIO | I, S | | OR-SD |
| | | CHAENOPSIDAE | | | | | | | | | |
| | | | *Neoclinus blanchardi* (Girard 1858) | Sarcastic fringehead | 2, 3 | | | LACM | | Southern limit | OR-SD |
| | | DACTYLOSCOPIDAE | | | | | | | | | |
| | | | *Gillellus semicinctus* (Gilbert 1890) | Halfbanded stargazer | 2 | | | SIO | | Northern limit | TEP |
| | | BLENNIIDAE | | | | | | | | | |
| | | | *Hypsoblennius gilberti* (Jordan 1882) | Rockpool blenny | 1, 2 | | 1, 2 | UABC | I | | SD |
| | | | *Hypsoblennius jenkinsi* (Jordan & Evermann 1896) | Mussel blenny | 1, 2 | 1, 2 | | UABC, SIO | I | | SD-CZ |
| | | | *Hypsoblennius gentilis* | Bay blenny | 1 | | 1 | | I | | SD-CZ |
| | | | *Ophioblennius steindachneri* (Jordan & Evermann 1898) | Panamic fanged blenny | 1, 2 | | 1, 2 | UABC | I, S | | TEP |
| | | | *Plagiotremus azaleus* (Jordan & Bollman 1890) | Sabertooth blenny | 1, 3 | | | | S | | SD-PA-POI |
| | | CALLIONYMIDAE | | | | | | | | | |
| | | | *Synchiropus atrilabiatus* (Garman 1899) | Blacklip dragonet | 3 | | | | | | SD-CH-POI |
| | | ELEOTRIDAE | | | | | | | | | |
| | | | *Eleotris picta* (Kner 1863) | Spotted sleeper | 2 | | | CICIMAR | | Range extension North | TEP |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PERCIFORMES (continued)** | | | | | | | | | | |
| | | GOBIIDAE | | | | | | | | | |
| | | | *Acanthogobius flavimanus* (Temminck & Schlegel 1845) | Yellowfin goby | 3 | | | | | Range extension South | NWP |
| | | | *Bathygobius ramosus* (Ginsburg 1947) | Panamic frillfin | 1, 2 | | 1 | UABC | I | Range extension North | TEP |
| | | | *Lepidogobius lepidus* (Girard 1858) | Bay goby | 3 | | | | | Southern limit | EP |
| | | | *Lythrypnus dalli* (Gilbert 1890) | Bluebanded goby | 1, 2 | 1, 2 | 1 | CICIMAR, LACM, SIO | S | | SD-PA-POI |
| | | | *Lythrypnus zebra* (Gilbert 1890) | Zebra goby | 2 | 1, 2 | 2 | LACM, SIO | S | | SD-CZ |
| | | | *Rhinogobiops nicholsii* (Bean 1882) | Blackeye goby | 1, 2, 3 | 1 | 1 | LACM | S | Southern limit | AL-SD |
| | | LUVARIDAE | | | | | | | | | |
| | | | *Luvarus imperialis* (Rafinesque 1810) | Louvar | 2 | | | SIO | | | CG |
| | | SPHYRAENIDAE | | | | | | | | | |
| | | | *Sphyraena argentea* (Girard 1854) | Pacific barracuda | 2 | | 1 | CICIMAR, SIO | S | | NEP |
| | | | *Sphyraena lucasana* (Gill 1863) | Cortez barracuda | 1, 2, 3 | | | UABCS | S | Northern limit | CZ-MX |
| | | TRICHIURIDAE | | | | | | | | | |
| | | | *Lepidopus fitchi* (Rosenblatt & Wilson 1987) | Pacific scabbardfish | 2 | | | CICIMAR, LACM | | | OR-CH |
| | | SCOMBRIDAE | | | | | | | | | |
| | | | *Sarda chiliensis* (Cuvier 1832) | Pacific bonito | 2 | | 2 | SIO | | | AL-PA |
| | | | *Scomber japonicus* (Houttuyn 1782) | Pacific chub mackerel | 2 | | | CICIMAR, SIO | | | TR |
| | | STROMATEIDAE | | | | | | | | | |
| | | | *Peprilus simillimus* (Ayres 1860) | Pacific pompano | 3 | | | | | | OR-CZ |
| | **COTTIFORMES** | | | | | | | | | | |
| | | HEXAGRAMMIDAE | | | | | | | | | |
| | | | *Ophiodon elongatus* (Girard 1854) | Lingcod | | | 1 | | S | Range extension South | AL-SD |
| | | | *Zaniolepis frenata* (Eigenmann & Eigenmann 1889) | Shortspine combfish | 2 | 2 | | LACM, SIO | | | OR-CZ |
| | | | *Zaniolepis latipinnis* (Girard 1858) | Longspine combfish | 2 | | | LACM, SIO | | | OR-SD |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **COTTIFORMES (continued)** | | | | | | | | | | |
| | | COTTIDAE | | | | | | | | | |
| | | | *Chitonotus pugetensis* (Steindachner 1876) | Soughback sculpin | 2 | 2 | | LACM | | | NEP |
| | | | *Clinocottus analis* (Girard 1858) | Woolly sculpin | 1, 2 | 1, 2 | 1, 2 | UABC, LACM, SIO | I | | OR-SD |
| | | | *Icelinus cavifrons* (Gilbert 1890) | Pit-head sculpin | 2 | | | LACM | | Southern limit | OR-SD |
| | | | *Icelinus fimbriatus* (Gilbert 1890) | Fringed sculpin | 3 | | | | | Range extension South | OR-SD |
| | | | *Icelinus quadriseriatus* (Lockington 1880) | Yellowchin sculpin | 2, 3 | | | CAS, LACM, SIO | | | OR-SD |
| | | | *Icelinus tenuis* (Gilbert 1890) | Spotfin sculpin | | 2, 3 | | LACM | | Southern limit | NEP |
| | | | *Ruscarius creaseri* | Roughcheek sculpin | 2 | | | SIO | | Southern limit | OR-SD |
| | | | *Scorpaenichthys marmoratus* (Ayres 1854) | Cabezon | 1, 2 | 2 | 1 | UABC, LACM, SIO | I, S | | AL-SD |
| | | ANOPLOPOMATIDAE | | | | | | | | | |
| | | | *Anoplopoma fimbria* (Pallas 1814) | Sablefish | | 2, 3 | | LACM | | Southern limit | NEP |
| | | AGONIDAE | | | | | | | | | |
| | | | *Agonopsis sterletus* (Gilbert 1898) | Southern spearnose poacher | 2 | | | LACM, SIO | | Southern limit | OR-CZ |
| | | | *Odontopyxis trispinosa* (Lockington 1880) | Pygmy poacher | 2 | | | LACM | | Southern limit | NEP |
| | | | *Xeneretmus ritteri* (Gilbert 1915) | Stripefin poacher | 3 | | | | | Southern limit | SD |
| | **PLEURONECTIFORMES** | | | | | | | | | | |
| | | PARALICHTHYIDAE | | | | | | | | | |
| | | | *Citharichthys fragilis* (Gilbert 1890) | Gulf sanddab | 2 | | | CAS, SIO | | | SD-CZ |
| | | | *Citharichthys sordidus* (Girard 1854) | Pacific sanddab | 2 | | | CICIMAR, LACM, SIO | | | AL-CZ |
| | | | *Citharichthys* sp. | | 2 | | | LACM | | | |
| | | | *Citharichthys stigmaeus* (Jordan & Gilbert 1882) | Speckled sanddab | 2 | 2 | | CICIMAR, LACM, SIO | | | AL-CZ |
| | | | *Citharichthys xanthostigma* (Gilbert 1890) | Longfin sanddab | 2 | 2 | | CICIMAR, SEMAR, CAS, LACM, SIO | | | SD-PA |
| | | | *Etropus crossotus* (Jordan & Gilbert 1882) | Fringed flounder | 2 | | | CICIMAR | | Northern limit | AA |
| | | | *Hippoglossina stomata* (Eigenmann & Eigenmann 1890) | Bigmouth sole | 2 | | | CICIMAR, LACM | | | OR-CZ |
| | | | *Paralichthys californicus* (Ayres 1859) | California halibut | 1, 2 | | | IBUNAM, CICIMAR | S | | OR-SD |
| | | | *Xystreurys liolepis* (Jordan & Gilbert 1880) | Fantail sole | 2 | | | LACM, SIO | | | OR-CZ |

*(continued)*

TABLE 2 (Continued)

**Systematic list of fishes of Cedros Archipelago, México, Northeastern Pacific. Classification according to Eschmeyer (2015). *Common name sensu Page et al. (2013); 1 = Fiel record, 2 = Museum recod, 3 = Literature; **Data from field surveys; ***BA = Biogeographic affinity: AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic province, PE = Peruvian province, POI = Pacific Oceanic Islands province, CG = Circumglobal, CT = Circumtropical, NWP = Northwestern Pacific, EP = Eastern Pacific, AA = AmphiAmerican. sensu Love et al. (2005) and Robertson and Allen (2015).**

| CLASS | ORDER | FAMILY | Scientific name | Common name* | Cedros | San Benito | Natividad | Museum data | Habitat** | Notes | BA*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ACTINOPTERI (continued)** | | | | | | | | | | | |
| | **PLEURONECTIFORMES (continued)** | | | | | | | | | | |
| | | BOTHIDAE | | | | | | | | | |
| | | | *Monolene asaedai* (Clark 1936) | Dark flounder | 3 | | | | | Range extension North | CZ-PA |
| | | PLEURONECTIDAE | | | | | | | | | |
| | | | *Glyptocephalus zachirus* (Lockington 1879) | Rex sole | 3 | | | | | Southern limit | NEP |
| | | | *Lyopsetta exilis* (Jordan & Gilbert 1880) | Slender sole | 2 | 2 | | CICIMAR, SIO | | | AL-SD |
| | | | *Parophrys vetulus* (Girard 1854) | English sole | 2 | | | SIO | | Southern limit | NEP |
| | | | *Pleuronichthys coenosus* (Girard 1854) | C-O sole | | | 2 | LACM | | Southern limit | AL-SD |
| | | | *Pleuronichthys decurrens* (Jordan & Gilbert 1881) | Curlfin sole | 2 | | | CAS | | Southern limit | AL-SD |
| | | | *Pleuronichthys ritteri* (Starks & Morris 1907) | Spotted turbot | 2 | | | LACM | | | OR-SD |
| | | | *Pleuronichthys verticalis* (Jordan & Gilbert 1880) | Hornyhead turbot | 2 | | 2 | CICIMAR, LACM, SIO | | | OR-CZ |
| | | CYNOGLOSSIDAE | | | | | | | | | |
| | | | *Symphurus atricaudus* (Jordan & Gilbert 1880) | California tonguefish | 2 | | | CICIMAR, CAS, LACM, SIO | | | OR-PA |
| | **TETRAODONTIFORMES** | | | | | | | | | | |
| | | BALISTIDAE | | | | | | | | | |
| | | | *Sufflamen verres* (Gilbert & Starks 1904) | Orangeside triggerfish | 1, 3 | | | | S | Northern limit | TEP |
| | | TETRAODONTIDAE | | | | | | | | | |
| | | | *Sphoeroides lobatus* (Steindachner 1870) | Longnose puffer | | | 1 | | S | | SD-CH |
| | | DIODONTIDAE | | | | | | | | | |
| | | | *Diodon holocanthus* (Linnaeus 1758) | Balloonfish | 2 | | | CICIMAR | | | CT |

TABLE 3

**Fish species that present range extension in their distribution in Cedros Archipelago. Reference corresponds to the most updated geographic distribution reference for these species. *Represents field records in this study.**

| Scientific Name | Reference | Extension to: | Northern End | Southern End |
|---|---|---|---|---|
| *Bathygobius ramosus** | Robertson and Allen, 2015 | North | 24.55 N | 06.11 S |
| *Eleotris picta* | Love et al. 2005 | North | 23.05 N | 09.25 S |
| *Halichoeres notospilus** | Robertson and Allen, 2015 | North | 26.13 N | 06.93 S |
| *Hemiramphus saltator* | Love et al. 2005 | North | 26.01 N | 09.25 S |
| *Lepophidium prorates* | Love et al. 2005 | North | 27.01 N | 05.10 S |
| *Monolene asaedai* | Love et al. 2005 | North | 24.51 N | 08.50 N |
| *Nannobrachium idostigma* | Love et al. 2005 | North | 27.20 N | 35.75 S |
| *Platybelone argalus* | Love et al. 2005 | North | 26.10 N | 35.75 S |
| *Prionotus ruscarius* | Love et al. 2005 | North | 26.00 N | 35.75 S |
| *Acanthogobius flavimanus* | Love et al. 2005 | South | 52.10 N | 32.68 N |
| *Chiasmodon niger* | Love et al. 2005 | South | 47.33 N | 32.43 N |
| *Gibbonsia montereyensis** | Love et al. 2005 | South | 53.75 N | 29.05 N |
| *Icelinus fimbriatus* | Love et al. 2005 | South | 53.50 N | 32.71 N |
| *Ophiodon elongatus** | Love et al. 2005 | South | 55.00 N | 29.61 N |
| *Phanerodon furcatus** | Love et al. 2005 | South | 40.60 N | 29.60 N |
| *Rhacochilus vacca** | Love et al. 2005 | South | 53.75 N | 29.03 N |
| *Sebastes flavidus* | Love et al. 2005 | South | 59.50 N | 30.49 N |
| *Sebastes hopkinsi** | Love et al. 2005 | South | 43.75 N | 29.03 N |
| *Sebastes paucispinis* | Love et al. 2005 | South | 59.50 N | 29.08 N |

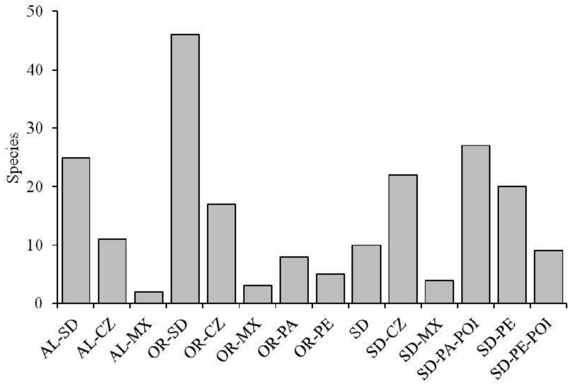

Figure 4. Distribution patterns of fish species of the Cedros Archipelago. (AL = Aleutian province, OR = Oregonian province, SD = San Diegan province, CZ = Cortez province, MX = Mexican province, PA = Panamic Province, PE = Peruvian province, POI = Pacific Oceanic Islands province)

rockpool blenny (*Hypsoblennius gilberti*), and the slender clingfish (*Rimicola eigenmanni*). Of these, the last four species were recorded in the field surveys at the CEA.

## DISCUSSION

A comprehensive systematic checklist of the CEA, with a total of 269 species, is presented here. The biogeographic relationships of the fish assemblages from the CEA showed a separation from its counterparts in northern Baja California and California. Most of the fish community at the CEA (50%) has a temperate affinity (warm-temperate and cold-temperate) and the CEA represents the distribution limit for 106 species (40% of the species reported). The distribution range extension for 19 species is documented.

Based on these results, the archipelago has high species richness, 50% of the known species for the entire San Diegan province (Miller and Lea 1976; Horn et al. 2006) and 15% of those in the Cortez province (Hastings et al. 2010; Palacios-Salgado et al. 2012), are reported in this small insular territory. The CEA might be richer than coastal lagoons and bays on the Baja California Peninsula (Danemann and De la Cruz-Agüero 1993; De la Cruz-Agüero et al. 1994, 1996; Rosales-Casián

1996; Galván-Magaña et al. 2000) and even comparable with larger islands in the Gulf of California (155–190 spp.: Del Moral et al. 2013) and with those islands in the Tropical Eastern Pacific (203–363 spp.: Robertson and Cramer 2009; Erisman et al. 2011).

The species richness found in the CEA is the result of a blend of species consisting of 3 large groups with patterns of geographical distribution: 1) temperate species (warm and cold temperate) with limited intrusion into subtropical waters (51% of the species), 2) tropical species with limited intrusion into warm-temperate waters, and 3) tropical species with extended incursion into temperate waters of the Eastern Pacific (eurythermal species).

Field records showed greater species richness in Cedros (78 species), followed by Natividad and San Benito Islands, with 56 and 54 species, respectively. Although sampling effort is an important factor in species record accumulation, the sampled area for Cedros, Natividad, and San Benito is equivalent in number of transects, but not for sampling sites. The proximity between islands could assume a similarity in the fish assemblage, however the area of the islands may be an important factor. The perimeter of the island is an indicator of habitat availability and therefore increasing potential to provide shelter for more species (Planes et al. 2012). This relationship could not be obvious on islands with similar perimeters, however, the perimeter of Cedros is 6-fold higher than Natividad and 8-fold higher than San Benito.

The resulting nMDS (based on subtidal field surveys from eleven North-Eastern Pacific islands) shows the qualitative differences in fish composition along the CEA and the Southern California Bight islands. This analysis does not show the similarity pattern between San Benito and some of the Channel Islands (California) found by Pondella et al. (2005). A group of 24 species have the largest dissimilarities contribution (78%) between sites; most of them have a tropical affinity (e.g., *Abudefduf troschelii*, *Apogon retrosella*, *Caulolatilus princeps*, *Halichoeres semicinctus*, and *Zapterix exasperata*). The overall differences in the species richness between our field records and previous studies in San Benito (i.e., Pondella et al. 2005) may be related to the inclusion of diverse habitats in the field surveys (i.e., tidepools, and soft bottom), but also by the new records of a these tropical affinity species to the assemblage. Furthermore, transitional regions may be strongly influenced by seasonality, where environmental conditions can be dominant for one of the two converging regions (Horn et al. 2006), therefore inducing a shift in the presence of fish assemblages.

Comparisons to other islands and coastal rocky ecosystems highlight the importance of the CEA in terms of connectivity between warm-temperate and tropical regions. Nevertheless, conservation and management mechanisms such as Marine Protected Areas, Marine Reserves, or Marine Refuges have not yet been implemented in this region to date, excluding a small Marine Reserve at Natividad Island implemented by local fishermen 2006 (Micheli et al. 2012).

The fact that the CEA represents the distribution limit of 106 species (40% of the species reported) is evidence of the biogeographic transition zone. It has been extensively documented that the biogeographic boundaries work diffusely and that their boundaries are movable in response to climatic factors (Hubbs 1960).

This study represents the southernmost distribution extension for 10 species, and the northernmost distribution extension for 9 species. These findings may be explained by the scarcity of field studies in the region, but nevertheless, previous studies (Quast 1968; Mearns 1988; Lea and Rosenblatt 2000; Pondella et al. 2005; Palacios-Salgado and Ramirez-Valdez 2011) have noted a trend of tropical species being recorded farther north of their previously recognized distribution, especially crossing Bahía Magdalena, a geographic feature traditionally recognized as a biogeographical barrier. These extensions of distribution range may represent an indicator of the warming trend observed in this biogeographic province (Pondella et al. 2005).

In addition to the range extensions documented in this study, the record of tropical affinity species that have been reported in San Diego or even farther north are included. However, most of these records have been associated with El Niño events (Mearns 1988; Lea and Rosenblatt 2000). As some of the species were abundant and recurrent at the CEA, the record of these species in the CEA would represent their northernmost stable populations.

It is important to highlight the presence of some species in the archipelago that were absent in previous studies in the peninsula (Danemann and De la Cruz-Agüero 1993; Ruiz-Campos et al. 2010). This is the case for *Thalassoma lucasanum*, *Ophioblennius steindachneri*, *Chromis atrilobata*, and *Bodianus diplotaenia*, which were recorded farther north in Guadalupe Island (Reyes-Bonilla et al. 2010). The presence of fish species in islands and their absence on the mainland has been explained before by structural habitat differences rather than oceanographic differences (Ebeling et al. 1980), and this pattern can be important to consider when seeking to set priority among conservation areas. It also highlights the record in the Mexican coast for the Yellowfin goby (*Acanthogobius flavimanus*), a native species from the Northwestern Pacific that has been reported on the coast of California (Workman and Merz 2007).

To our knowledge, the presence of endemic species has not been recognized for the CEA. The record of *Gibbonsia norae* as an endemic species of Guadalupe Island

and San Benito (Hubbs 1960; Reyes-Bonilla et al. 2010) is now accepted as a semi-isolated population of *G. montereyensis* (Stepien and Rosenblatt 1991). Even though the proximity to the mainland may partly explain this absence of endemism, it is also known that limited endemism exists in the fish fauna of the west coast of the Baja California peninsula (Hubbs 1960).

This study demonstrates the importance of complementing recent underwater surveys with historical and museum records to prepare baseline information potentially useful for the conservation and management of fish communities. The CEA plays a key role on the connectivity in the biogeographic transition zone on the Pacific coast of the Baja California Peninsula.

## SUMMARY

We documented the presence of 269 fish species in the Cedros Archipelago, and 105 species were recorded during field surveys. The observed species richness at the CEA may be the result of the confluence of three biogeographic provinces in the Pacific coast of Baja California peninsula, in addition to the proximity of the archipelago to the mainland coast and past terrestrial connection with the peninsula. Although habitat heterogeneity is an important factor in this ecosystem, our biogeographical analyses allowed us to identify the representation of 14 distribution patterns in the fish assemblage.

The biogeographic transition has a significant impact on the composition of fish communities is this region. That is evident when half of the species have temperate affinity and the rest is composed of species of tropical affinity and wide distribution. In addition, the implication as a biogeographic frontier is when the archipelago represents the distribution limit for 40% of registered species. Finally, the biogeographic analysis showed the low similarity between this island and its northern counterparts, marking the beginning of the transition to a subtropical region.

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## REFERENCES

Aguilar-Rosas, L. E., S. Min Boo, F. Correa-Sandoval, A. Ramírez-Valdez, I. Giffard-Mena, and C.V. Aguilar-Rosas. 2011. First record of *Dictyopteris prolifera* (Dictyotales: Phaeophyceae) on the Eastern Pacific coast. Marine Biodiversity Records 4:1–5.

Aguirre-Munoz, A., D. A. Croll, C. J. Donlan, R. W. Henry III, M. A. Hermosillo, G. R. Howald, et al. 2008. High-impact conservation: Invasive mammal eradications from the islands of western Mexico. *Ambio*, 37, 101–107.

Briggs, J. C. 1955. A monograph of the clingfishes (Order Xenopterygii). *Stanford Ichthyol Bull*, 6, 1–224.

Briggs, J. C. 1974. *Marine Zoogeography*. McGraw-Hill, New York. 475 pp.

Busby-Spera, C. J. 1988. Evolution of a Middle Jurassic back-arc basin, Cedros Island, Baja California: Evidence from a marine volcaniclastic apron: Geological Society of America Bulletin, v. 100(2): 218–233.

Carpizo-Ituarte, E., A. Ramírez-Valdez, F. Correa-Sandoval, L. Aguilar-Rosas, I. Giffard-Mena, R. Escobar-Fernandez, and G. Montano-Moctezuma. 2012. Assessing a marine biogeographic transition zone: biogeographic patterns of the tidepools fishes of Isla de Cedros, Mexico. *In:* Hortal, J., K. Faller, K. Feeley, R. Field, et al. 2012. Conference program and abstracts. International Biogeography Society 6th Biennial Meeting 9–13 January 2013, Miami, Florida, USA. Frontiers of Biogeography, 4(5).

Castro-Aguirre, J. L., and H. Espinosa-Pérez. 1996. Catálogo sistemático de las rayas y especies afines de México (Chondrichthyes: Elasmobranchii: Rajiformes: Batoideiomorpha). México: Instituto de Biología, Universidad Nacional Autónoma de México, Listados Faunísticos de México 8:75.

Clarke, K. R., and R. N. Gorley. 2006. Primer v6. User manual/tutorial. Primer-E Ltd. Plymouth. 190 pp.

Danemann, G. D., and J. De la Cruz-Agüero. 1993. Ictiofauna de la Laguna de San Ignacio, B.C.S., México. Ciencias Marinas 19: 333–341.

De la Cruz-Agüero, J., F. M. Galván, A. C. Abitia, J. R. Rodríguez, and F. J. Gutiérrez. 1994. Lista sistemática de los peces marinos de bahía Magdalena, Baja California Sur, México. Ciencias Marinas 20: 17–31.

De la Cruz-Agüero, J., M. Arellano-Martínez, and V. M. Cota-Gómez. 1996. Lista sistemática de los peces marinos de las Lagunas Ojo de Liebre y Guerrero Negro, B.C.S. y B.C., México. Ciencias Marinas 22: 111–128.

Del Moral-Flores, L. F., A. F. González-Acosta, H. Espinosa-Pérez, G. Ruiz-Campos, and J. L. Castro-Aguirre. 2013. Annotated checklist of the ichthyofauna from the islands of the Gulf of California, with comments on its zoogeographic affinities. Revista Mexicana de Biodiversidad 84: 184–214.

Des Lauriers, M. R. 2010. Island of Fogs: Archaeological and Ethnohistorical Investigations of Isla Cedros, Baja California. Salt Lake City: University of Utah Press.

Ebeling, A. W., R. J. Larson, and W. S. Alevizon. 1980. Habitat Groups and Island-Mainland Distribution of Kelp-bed Fishes off Santa Barbara, CA. In: Proceedings of the 2nd California Islands Multidisciplinary Symposium. 403–431.

Erisman, B. E, G. R. Galland, I. Mascareñas, J. Moxley, H. J. Walker, O. Aburto-Oropeza, P. A. Hastings, and E. Ezcurra. 2011. List of coastal fishes of Islas Marías archipelago, Mexico, with comments on taxonomic composition, biogeography, and abundance. Zootaxa 2985: 26–40.

Eschmeyer, W. N. (ed). Catalog of fishes: genera, species, references. (http://research.calacademy.org/research/ichthyology/catalog/fishcatmain.asp). Electronic version accessed 14 oct 2014. [This version was edited by Bill Eschmeyer.]

Espinosa-Pérez, H., J. L. Castro-Aguirre, and L. Huidobro-Campos. 2004. Listados faunísticos de México. IX. Catálogo sistemático de tiburones (Elasmobranchii: Selachimorpha). Universidad Nacional Autónoma de México, México.

Félix-Uraga, R., R. M. Alvarado-Castillo, and R. Carmona-Piña. 1996. The sardine fishery along the western coast of Baja California, 1981 to 1994. California Cooperative Oceanic Fisheries Investigations Reports 37: 188–192.

Fischer, W., F. Krupp., W. Schneider., C. Sommer., K. E. Carpenter., and V. H. Niem. 1995. Guia FAO para la identificación de especies para los fines de pesca. Pacífico Centro-Oriental. (Vol- II–III). FAO.

Hastings, P. A. 2000. Biogeography of the tropical eastern Pacific: distribution and phylogeny of chaenopsid fishes. *Zoological Journal of the Linnean Society* 128:319–335.

Hastings, P. A., L. T. Findley, A. M. Van der Heiden. 2010. Fishes of the Gulf of California. Pp: 96–118. In: Brusca R. (ed.). The Gulf of California. Biodiversity and Conservation. University Arizona Press. Tucson, AZ, USA.

Hickey, B. M. 1979. The California Current System-hypothesis and facts. Progress in Oceanography 8:191–279.

Hoese, F. D., and S. Reader. 2001. A preliminary review of the eastern Pacific species of *Elacatinus* (Perciformes: Gobiidae). Rev Biol Trop 49 (Supl. 1): 157–167.

Horn, M. H., L. G. Allen, and R. N. Lea. 2006. Biogeography. *In*: The ecology of marine fishes. California and adjacent waters, L. G. Allen, D. J. Pondella and M. H. Horn, eds. Berkeley: University of California Press. pp. 3–25.

Hubbs, C. L. 1953. Revision of the Eastern Pacific fishes of the clinid fish genus *Labrisomus. Zoologica* 38(3):113–136.

Hubbs, C. L. 1960. The marine vertebrates of the outer coast. Symposium The Biogeography of Baja California and adjacent seas. Systematic Zoology 9:134–147.

Huey, L. M. 1942. Two new wrens and a new jay from Lower California, Mexico. Transactions of the San Diego Society of Natural History. Vol IX (35):427–434.

Kessler, W. S. 2006. The circulation of the eastern tropical Pacific: A review, Progress in Oceanography, Volume 69, Issues 2–4, May–June 2006, Pages 181–217.

Kruskal, J. B., and M. Wish. 1978. Multidimensional scaling, Sage Publications, Beverly Hills. 487 pp.

Lea, R. N., and R. H. Rosenblatt. 2000. Observations on fishes associated with the 1997–98 El Niño off California. California Cooperative Oceanic Fisheries Investigations Reports. 41:117–129.

Littler, M. M. 1980. Overview of the rocky intertidal systems of southern California. Multidisciplinary symposium on the California Islands (ed. by D. M. Power), pp. 265–306. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Love, M. S., C. W. Mecklenburg, T. A. Mecklenburg, and L. K. Thorsteinson. 2005. Resource inventory of marine and estuarine fishes of the west coast and Alaska: A checklist of north Pacific and Arctic ocean species from Baja California to the Alaska-Yukon Border. U.S. Department of the Interior, U.S. Geological Survey, Biological Resources Division, Washington. 276 pp.

Mearns, A. J. 1988. The "odd fish": unusual occurrences of marine life as indicators of changing ocean conditions. In Marine organisms as indicators, (D. F. Soule and G. S. Kleppel (eds.). Springer-Verlag, New York, pp. 137–176.

Mellink, E. 1993. Biological conservation of Isla de Cedros, Baja California, México: assessing multiple treats. *Biodiversity and Conservation*, 2:62–69.

Micheli, F., A. Saenz-Arroyo, A. Greenley, L. Vazquez, J. A. Espinoza-Montes, M. Rosseto, and G. A. De Leo. 2012. Evidence that Marine Reserves Enhance Resilience to Climatic Impacts. *PLoS ONE*, 7(7):e40832.

Miller, A. J., J. C. McWilliams, N. Schneider, J. S. Allen, J. A. Barth, R. C. Beardsley, F. P. Chavez, T. K. Chereskin, C. A. Edwards, R. L. Haney, K. A. Kelly, J. C. Kindle, L. N. Ly, J. R. Moisan, M. A. Noble, P. P. Niiler, L. Y. Oey, F. B. Schwing, R. K. Shearman, and M. S. Swenson. 1999. Observing and modeling the California Current System. *Eos Transactions, American Geophysical Union* 80:533–9.

Miller, J. D., and N. R. Lea. 1972. Guide to the coastal marine fishes of California. *Fish. Bull.* 157: 1–249.

Oberbauer, T. A.1985. Floristic Analysis of Vegetation Communities on Isla de Cedros, Baja California, Mexico. *Pest Control* 1:75–82.

Page, L. M., H. Espinosa-Pérez, L. T. Findley, C. R. Gilbert, R. N. Lea, N. E. Mandrak, and R. L. Mayden. 2013. Common and scientific names of fishes from the United States, Canada, and Mexico, 7th edn. Spec Publ Am Fish Soc No. 34, Bethesda, MD.

Palacios-Salgado, D. S., and A. Ramirez-Valdez. 2011. New Records of Demersal Fishes in the Northwest of Mexico. J. Fisheries and Aquatic Science. 6(1): 93–100.

Palacios-Salgado, D. S., L. A. Burnes-Romo, J. J. Tavera, and A. Ramírez-Valdez. 2012. Endemic fishes of the Cortez biogeographic province (Eastern Pacific Ocean). Acta Ichthyologica Et Piscatoria 42 (3): 153–164.

Planes, S., D. Lecchini, C. Mellin, J. C. Charton, M. Harmelin-Vivien, M. Kulbicki, G. Mou-Tham, and R. Galzin. 2012. Environmental determinants of coral reef fish diversity across several French Polynesian atolls. Comptes Rendus Biologie 335: 417–423.

Pondella, D. J. II, B. E. Gintert, J. R. Cobb, and L. G. Allen. 2005. Biogeography of the nearshore rocky-reef fishes at the southern and Baja California islands. Journal of Biogeography 32:187–201.

Quast, J. C. 1968. Fish fauna of the rocky inshore zone. Utilization of kelp-bed resources in southern California (ed. By W. J. North and C. L. Hubbs), pp. 35–55. California Department of Fish and Game, Fish Bulletin, 139, 1–264.

Quiñonez-Velázquez, C., R. Alvarado-Castillo, and R. Félix-Uraga. 2002. Relación entre el crecimiento individual y la abundancia de la población de la sardina del Pacífico *Sardinops caeruleus* (Pisces: Clupeidae) (Girard 1856) en Isla de Cedros, Baja California, México. Revista de Biología Marina y Oceanografía 37 (1): 1–8.

Reyes-Bonilla, H., A. Ayala-Bocos, S. González-Romero, I. Sánchez-Alcántara, M. Walther-Mendoza, Y. R. Bedolla-Guzmán, A. Ramírez-Valdez, L. E. Calderón-Aguilera, and N. C. Olivares-Bañuelos. 2010. Checklist and biogeography of fishes from Guadalupe Island, Western México. Cal Coop Ocean Fish Invest Rep 51:195–209.

Richards, D.V. 2000. The status of rocky intertidal communities in the Channel Islands National Park. Proceedings of the fifth California Islands symposium (ed. by D. R. Browne, K. L. Mitchell and H.W. Chaney), pp. 356–358. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Robertson, D. R., and G. R. Allen. 2015. Shore fishes of the Tropical Eastern Pacific: an information system on line. Ver 1.0 (2015). Smithsonian Tropical Research Institute, Balboa, Panamá. www.neotropicalfishes. org/sftep Robertson et al. (2004).

Robertson, D. R., and K. L. Cramer. (2009) Shore fishes and biogeographic subdivisions of the tropical Eastern Pacific. Marine Ecology Progress Series, 380, 1–17.

Rodriguez Valencia, J. A., F. Caballero Alegria, and J. Castro Gonzalez. 2004. Tendencias de temporales (1989–99) en las poblaciones de Haliotis fulgens y H. corrugata (Gastropoda: Haliotidae) de Isla Cedros, Baja California, México. Ciencias Marinas 30:489–501.

Rosales-Casián, J. A. 1996. Ichthyofauna of Bahía de San Quintín, Baja California, México and its adjacent coast. Cienc. Marinas 22:443–458.

Ruiz-Campos, G., A. Ramírez-Valdez, S. González-Guzmán, J. L. Castro-Aguirre, A. F. González-Acosta, and J. De La Cruz-Agüero. 2010. Composition, density and biogeographical affinities of the rocky intertidal fishes on the western coast of the Baja California peninsula, Mexico. California Cooperative Oceanic Fisheries Investigations Reports Vol. 51: 210–220.

Stephens, J. S. 1963. A revised classification of the blennioid fishes of the American family Chaenopsidae. University of California Publications. Zoology 68:1–165.

Stephens, J. S., E. S. Hobson, and R. K. Johnson. 1966. Notes on distribution, behavior and morphological variation in some Chaenopsid fishes from the Tropical Eastern Pacific with descriptions of two new species, *Acanthemblemaria castroi* and *Coralliozetus springeri*. Copeia 3:424–438.

Stepien, C. A., and R. H. Rosenblatt. 1991. Patterns of gene flow and genetic divergence in the northeastern pacific clinidae teleostei blennioidei based on allozyme and morphological data. *Copeia*, 873–896.

Taylor, R. E., J. Southon, and M. R. Des Lauriers. 2007. Holocene marine reservoir time series ΔR values from Cedros Island, Baja California. Radiocarbon, Vol 49(2): 899–904.

Wiley, E. O., and D. Johnson. 2010. A teleost classification based on monophyletic groups. In: Nelson, J.S., H. P. Schultze, M. V. H. Wilson (eds). Origin and Phylogenetic Interrelationships of Teleosts. Pfeil, München, pp 123–182.

Workman, M. L., and J. E. Merz. 2007. Introduced yellowfin goby, Acanthogobius flavimanus: Diet and habitat use in the Lower Mokelumne River, California. San Francisco. Estuary and Watershed Science 5(1).

# CHAPTER 2:

# Asymmetry in the management of marine resources across political borders

ARTURO RAMÍREZ-VALDEZ

## OVERVIEW

In marine environments, political borders divide fish populations and their critical habitats (Block et al., 2011; Chabot, Hawk, & Allen, 2015; Selkoe, Vogel, & Gaines, 2007). These imaginary lines cause asymmetry in research, management, and conservation for otherwise well-connected fish populations. Asymmetry in research across a political border can generate differences in species knowledge and therefore impact the perception of the status of populations. Similarly, the asymmetric management of a fishery also impacts the economy derived from it, the subsistence of its populations, and can compromise neighboring populations. Coordinated management of connected populations may allow for the replenishment of depleted stocks, improve population stability, and ultimately maintain genetic diversity (Paterson et al., 2015). Although it is reasonable to argue that effective management can be achieved through cooperation and symmetric management goals, the benefits themselves are then often unequal (Ishimura et al., 2013). The asymmetry in the research and management of shared resources between nations can be driven by a variety of factors, including differing perceptions of the importance of a resource, economic and social disparity, and different management goals (Miller and Munro, 2004).

In terms of fisheries, scientific evidence suggest that cooperative management of shared marine stocks is necessary to achieve sustainability and reduce uncertainty in future stock predictions (Ishimura et al., 2013; Pinsky et al., 2018). By some estimates, there may be as many as 1,500 "shared stocks" worldwide, with only a few being effectively and cooperatively managed (Caddy, 1997). The United Nations Convention on the Law of the Sea (UNCLOS) grants each country exclusive rights to set its own goals in the management and evaluation of resources within its exclusive economic zones (EEZs); therefore, in most cases these decisions are made without regard to neighboring states (UN, 1982). However, UNCLOS states that nations must ensure that the fisheries within their EEZ are not overexploited, and in the case of shared resources, nations must cooperate to establish adequate management measures (Pinsky et al., 2018).

A growing body of literature provides tools for navigating the complexities of transboundary shared stock management (Miller and Munro, 2004; Pinsky et al., 2018). However, currently theoretical and modeling studies are still dominant over empirical studies. Both theoretical and modeling studies have shown that long-term agreements based on scientific information incorporating variability in stock abundance allows for the maintenance of collaborative interest and improves country-specific benefits (Miller and Munro, 2004; Pinsky et al., 2018). The challenges we face in the management of shared resources have been known for a long time, and as climate change adds more potential stressors to fish stocks (Cavole et al., 2016; Pinsky et al., 2018), it is imperative that we take action. Lack of collaboration between countries results in an asymmetry in the management of marine resources that may not be successful in the long term, particularly in the context of climate change (Pinsky et al., 2018). However, appropriate management of resources may offset potentially negative effects of climate change (Free et al., 2020; Gaines et al., 2018).

Thus, there are three arguments for the importance of binational cooperation in the management of shared marine resources between the United States (U.S.) and Mexico:

1. First, the marine environment off the coast of California (U.S.) and Baja California (Mexico) is part of the California Current System, which is considered a single marine ecoregion (Horn et al., 2006). Throughout the California Current System, species maintain genetic connectivity and rely on critical habitats on both sides of the political border (Block et al., 2011; Paterson et al., 2015; Selkoe et al., 2007).
2. Second, the government regulations of both countries recognize the potential contribution of marine population sources from the other country. The California Marine Life Management Act encourages regional approaches to marine management and pays particular attention to coordinated approaches to the management of shared fisheries (Leet et al., 2001). Mexico is a signatory to international agreements for cooperation in the management of shared resources, such as the Code of Conduct for Responsible Fisheries and the Mexus-Pacific Cooperative Agreement. The Baja California state fisheries management agency highlights the need for international cooperation for data access and stock assessment.
3. Third, although the ocean is experiencing increasingly rapid changes that are consequently causing species to move to new locations, our management vision remains static (Miller and Munro, 2004; Pinsky et al., 2018). Asymmetry is thus not a steady-state issue, but rather a dynamic one that is exacerbated as the distribution of fishery stocks shift, the social

and economic situation of nations change, and environmental stressors become more erratic (Aburto-Oropeza et al., 2018; Cavole et al., 2016).

The border that divides California and Baja California is one of the most asymmetric and complex political borders in the world. Despite being strongly connected through history, culture, economy, and natural resources, the disparity between California and Baja California is evident. While California is the world's fifth largest economy with a Gross Domestic Product (GDP) of US$3.2 trillion, Baja California's GDP is <1% of that at just US $29 billion. Both countries have seen sharp rises in population over the past 100 years, but as of 2020, the population of California is 39.99 million people, whereas the population of Baja California is only 3.8 million (U.S. Census Bureau; Mexico National Institute of Statistics and Geography-INEGI). Population growth has increased pressure on local ecosystem services and signs of over-exploitation, such as overfishing, have been documented in the region (Erisman et al., 2011; Ganster, 2009; Shaw et al., 2011; Tegner & Dayton, 2000).

## REFERENCES

Aburto-Oropeza, O., Johnson, A.F., Agha, M., Allen, E.B., Allen, M.F., González, J.A., Arenas Moreno, D.M., Beas-Luna, R., Butterfield, S., Caetano, G., Caselle, J.E., Gaytán, G.C., Castorani, M.C.N., Cat, L.A., Cavanaugh, K., Chambers, J.Q., Cooper, R.D., Arafeh-Dalmau, N., Dawson, T., de la Vega Pérez, A.D., DiMento, J.F.C., Guerrero, S.D., Edwards, M., Ennen, J.R., Estrada-Medina, H., Fierro-Estrada, N., Gadsden, H., Galina-Tessaro, P., Gibbons, P.M., Goode, E. V., Gorris, M.E., Harmon, T., Hecht, S., Heredia Fragoso, M.A., Hernández-Solano, A., Hernández-Cortés, D., Hernández-Carmona, G., Hillard, S., Huey, R.B., Hufford, M.B., Jenerette, G.D., Jiménez-Osornio, J., López-Nava, K.J., Lara Reséndiz, R.A., Leslie, H.M., López-Feldman, A., Luja, V.H., Méndez, N.M., Mautz, W.J., Medellín-Azuara, J., Meléndez-Torres, C., de la Cruz, F.R.M., Micheli, F., Miles, D.B., Montagner, G., Montaño-Moctezuma, G., Müller, J., Oliva, P., Ortinez Álvarez, J.A., Ortiz-Partida, J.P., Palleiro-Nayar, J., Páramo Figueroa, V.H., Parnell, P.E., Raimondi, P., Ramírez-Valdez, A., Randerson, J.T., Reed, D.C., Riquelme, M., Torres, T.R., Rosen, P.C., Ross-Ibarra, J., Sánchez-Cordero, V., Sandoval-Solis, S., Santos, J.C., Sawers, R., Sinervo, B., Sites, J.W., Sosa-Nishizaki, O., Stanton, T., Stapp, J.R., Stewart, J.A.E., Torre, J., Torres-Moye, G., Treseder, K.K., Valdez-Villavicencio, J., Valle Jiménez, F.I., Vaughn, M., Welton, L., Westphal, M.F., Woolrich-Piña, G., Yunez-Naude, A., Zertuche-González, J.A., Taylor, J.E., 2018. Harnessing cross-border resources to confront climate change. Environ. Sci. Policy 87, 128–132. https://doi.org/10.1016/j.envsci.2018.01.001

Block, B.A., Jonsen, I.D., Jorgensen, S.J., Winship, A.J., Shaffer, S.A., Bograd, S.J., Hazen, E.L., Foley, D.G., Breed, G.A., Harrison, A.L., Ganong, J.E., Swithenbank, A., Castleton, M., Dewar, H., Mate, B.R., Shillinger, G.L., Schaefer, K.M., Benson, S.R., Weise, M.J., Henry, R.W., Costa, D.P., 2011. Tracking apex marine predator movements in a dynamic ocean. Nature 475, 86–90. https://doi.org/10.1038/nature10082

Caddy, J.F., 1997. Establishing a consultative mechanism or arrangement for managing shared stocks within the jurisdiction of contiguous states, in: Taking Stock: Defining and Managing Shared Resources. Australian Society for Fish Biology and Aquatic Resource Management Association of Australasia Joint Workshop Proceedings, p. 16.

Cavole, L.M., Demko, A.M., Diner, R.E., Giddings, A., Koester, I., Pagniello, C.M.L.S., Paulsen, M.-L., Ramirez-Valdez, A., Schwenck, S.M., Yen, N.K., Zill, M.E., Franks, P.J.S., 2016. Biological impacts of the 2013–2015 warm-water anomaly in the northeast Pacific: Winners, Losers, and the Future. Oceanography 29. https://doi.org/10.5670/oceanog.2016.32

Chabot, C.L., Hawk, H.A., Allen, L.G., 2015. Low contemporary effective population size detected in the Critically Endangered giant sea bass, Stereolepis gigas, due to fisheries overexploitation. Fish. Res. 172, 71–78. https://doi.org/10.1016/j.fishres.2015.06.015

Erisman, B.E., Allen, L.G.L., Claisse, J.J.T., Pondella, D.J., Miller, E.F., Murray, J.H., Pondella II, D.J., Miller, E.F., Murray, J.H., 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Can. J. Fish. Aquat. Sci. 68, 1705–1716. https://doi.org/10.1139/f2011-090

Free, C.M., Mangin, T., Molinos, J.G., Ojea, E., Burden, M., Costello, C., Gaines, S.D., 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PLoS One 15, 1–21. https://doi.org/10.1371/journal.pone.0224347

Gaines, S.D., Costello, C., Owashi, B., Mangin, T., Bone, J., Molinos, J.G., Burden, M., Dennis, H., Halpern, B.S., Kappel, C. V., Kleisner, K.M., Ovando, D., 2018. Improved fisheries management could offset many negative effects of climate change. Sci. Adv. 4, 1–8. https://doi.org/10.1126/sciadv.aao1378

Ganster, P., 2009. Sustainable Development and the U.S.-Mexico Border Region. Public Adm. Rev. 69, 153–155. https://doi.org/10.1111/j.1540-6210.2008.01957.x

Horn, M., Allen, L.G., Lea, R.N., 2006. Biogeography, in: The Ecology of Marine Fishes: California and Adjacent Waters.

Ishimura, G., Herrick, S., Sumaila, U.R., 2013. Fishing games under climate variability: Transboundary management of Pacific sardine in the California Current System. Environ.

Econ. Policy Stud. 15, 189–209. https://doi.org/10.1007/s10018-012-0048-0

Leet, W.S., Dewees, C.M., Klingbeil, R., Larson, E.J., 2001. California's Living Marine Resources: A Status Report, California Department of Fish and Game. University of California Press, Davis, CA.

Miller, K.A., Munro, G.R., 2004. Climate and cooperation: A new perspective on the management of shared fish stocks. Mar. Resour. Econ. 19, 367–393. https://doi.org/10.1086/mre.19.3.42629440

Paterson, C.N., Chabot, C.L., Robertson, J.M., Erisman, B., Cota-Nieto, J.J., Allen, L.G., 2015. The genetic diversity and population structure of barred sand bass, Paralabrax nebulifer: A historically important fisheries species off southern and Baja California. Calif. Coop. Ocean. Fish. Investig. Reports 56, 1–13.

Pinsky, M.L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., Cheung, W.W.L., 2018. Preparing ocean governance for species on the move. Science (80-. ). 360, 1189–1191. https://doi.org/10.1126/science.aat2360

Selkoe, K., Vogel, A., Gaines, S., 2007. Effects of ephemeral circulation on recruitment and connectivity of nearshore fish populations spanning Southern and Baja California. … Ecol. Ser. … 351, 209–220.

Shaw, M.R., Pendleton, L., Cameron, D.R., Morris, B., Bachelet, D., Klausmeyer, K., Mackenzie, J., Conklin, D.R., Bratman, G.N., Lenihan, J., Haunreiter, E., Daly, C., Roehrdanz, P.R., 2011. The impact of climate change on California ' s ecosystem services 109, 465–484. https://doi.org/10.1007/s10584-011-0313-4

Tegner, M.J., Dayton, P.K., 2000. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

“Case Study 1”

# Asymmetry across political borders: research, management, and economic value of the critically endangered Giant Sea Bass (*Stereoleopis gigas*)

## ABSTRACT

Asymmetry in the exploitation, knowledge, management, and economic value of transboundary fishery stocks can create a complex scenario for resource sustainability and undermine conservation efforts. The giant sea bass (GSB; *Stereolepis gigas*) is the largest coastal bony fish in California, United States (U.S.) and Baja California (Mexico) waters and a critically endangered species with immense cultural and ecological value. As a result of overfishing and subsequent declines in their populations, strong conservation regulations to protect GSB were imposed in the U.S. waters; regulations in Mexico remain almost non-existent. The collapse of GSB populations in California occurred before any effort to understand the basic biology of the species or its population size. And while there is an ongoing fishery in Mexican waters, research on this species is absent. This study analyzes how the asymmetry in knowledge and management between the U.S. and Mexico may represent a challenge for the conservation and sustainability of this critically endangered species. Our work combines historical and contemporary GSB fishery data from the U.S. and Mexico to provide a broad perspective of this population and current conservation threats. Over the past two decades, and despite a fishery ban, an annual average of 3-tons has been landed as a by-catch in the U.S. Meanwhile, GSB landings (2000-2016) in Mexico averaged 50 tons per year, a quarter of its average totals during the prior century. Based on Mexican landings and the average weight of landed fish, this represents an estimate of 2,120 individuals harvested annually. Fish-market records show that the Mexican GSB fishery is significantly composed of immature individuals (48%). The observed differences in history of interventions and current population trends highlights the importance of the much-needed international cooperation to manage transboundary resources.

## INTRODUCTION

In the marine environment, political borders divide fish populations and their critical habitats (Block et al., 2011; Chabot, Hawk, & Allen, 2015; Selkoe, Vogel, & Gaines, 2007). These imaginary lines cause asymmetry in research, management, and conservation for otherwise well-connected fish populations. Asymmetry in research across a political border can generate differences in a species knowledge and then impact the perception of the status of populations. Similarly, the asymmetric management of a fishery also impacts the economy derived from it, and the subsistence of its populations, but can also compromise neighboring populations. Coordinated management of connected populations may allow for the replenishment of depleted stocks, improve population stability, and ultimately maintain genetic diversity (Paterson et al., 2015). Although it is reasonable to argue that effective management can be achieved through cooperation and symmetric management goals, benefits themselves are then often unequal (Ishimura et al., 2013a). The asymmetry in the research and management of shared resources between nations can be driven by a variety of factors, including differing perceptions of the importance of a resource, economic and social disparity, and different management goals (Miller and Munro, 2004).

Evidence suggest that cooperative management of shared fisheries marine stocks is necessary to achieve sustainability and reduce uncertainty in future stock predictions (Ishimura et al., 2013a; Pinsky et al., 2018). By some estimates, there may be as many as 1,500 "shared stocks" worldwide, with only a few being effectively and cooperatively managed (Caddy, 1997). The United Nations Convention on the Law of the Sea (UNCLOS) grants each country exclusive rights to set its own goals in the management and evaluation of resources within its exclusive economic zones (EEZs); therefore, in most cases these decisions are made without regard to neighbor states (UN, 1982). However, UNCLOS states that nations must ensure that the fisheries within their EEZ are not overexploited, and in the case of shared resources, nations must cooperate to establish adequate management measures (Pinsky et al., 2018). A growing body of literature provides tools for navigating the complexities of transboundary shared stock management (Miller and Munro, 2004; Pinsky et al., 2018). The challenges we face in the management of shared resources have been known for a long time, and as climate change adds more potential stressors to fish stocks (Cavole et al., 2016; Pinsky et al., 2018), it is imperative that we take action. Lack of collaboration between countries results in an asymmetry in the management of marine resources that may not be successful in the long term, particularly in the context of climate change (Pinsky et al., 2018).

However, appropriate management of resources may offset the potentially negative effects of climate change (Free et al., 2020; Gaines et al., 2018).

There are three common arguments for the importance of binational cooperation in the management of shared marine resources between the U.S. and Mexico: a) species and habitat connectivity (Romo-Curiel et al., 2016), b) government management regulations (Cisneros-Montemayor et al., 2020; Munro, 2018), and c) climate uncertainty (Pinsky et al., 2018). First, the marine environment off the coast of California and Baja California is part of the California Current System, which is considered a single marine ecoregion (Horn et al., 2006). Throughout the California Current System, species maintain genetic connectivity and rely on critical habitats on both sides of the political border (Block et al., 2011; Paterson et al., 2015; Selkoe et al., 2007). Second, government regulations of both countries recognize the potential contribution of population sources in the other country. The California Marine Life Protection Act encourages regional approaches to marine management and pays particular attention to coordinated approaches to the management of shared fisheries (Leet et al., 2001). Mexico is a signatory to international agreements for cooperation in the management of shared resources, such as the Code of Conduct for Responsible Fisheries and the Mexus-Pacifico Cooperative Agreement. The Baja California state fisheries management agency (the State Fishery Inventory) highlights the need for international cooperation for data access and stock assessment (Baja California State Government, 2017). Third, although the ocean is experiencing increasingly rapid changes that are consequently causing species to move to new locations, our management vision remains static (Miller and Munro, 2004; Pinsky et al., 2018). Asymmetry is thus not a steady-state issue, but rather a dynamic one that is exacerbated as the distribution of fishery stocks shift, the social and economic situation of nations changes, and environmental stressors become more erratic (Aburto-Oropeza et al., 2018; Cavole et al., 2016).

The border that divides California (U.S.) and Baja California (Mexico) is one of the most asymmetric and complex political borders in the world. California and Mexico are strongly connected through history, culture, economy, and natural resources. Despite this, there is an evident disparity. While California is the world's fifth largest world economy with a Gross Domestic Product (GDP) of US$3.2 trillion, the Baja California GDP is <1% of that at just US$29 billion. Both countries have seen sharp rises in population over the past 100 years, but as of 2020, the population of California is 39.99 million people, whereas the population of Baja California is 3.8 million (U.S. Census Bureau; Mexico National Institute of Statistics and Geography-INEGI). Population growth has increased pressure on local ecosystem services, and signs of over-exploitation, such as overfishing, have been documented in the region (Erisman et al., 2011; Ganster, 2009; Shaw et al., 2011; Tegner & Dayton, 2000).

An emblematic case of asymmetry in the management of the marine resources between the U.S. and Mexico is the critically endangered giant sea bass (*Stereolepis gigas,* GSB), whose distribution ranges from Humboldt Bay in northern California to the Baja California peninsula and throughout the Gulf of California (Cornish, 2004; Love et al., 2005). The GSB is the largest coastal bony fish in the Northeastern Pacific, growing up to 2.7 m and is a keystone species with a cultural and economic relevance (Allen, 2017; Love, 2012). GSBs play an important function in structuring their ecosystems (Allen, 2017; Hawk and Allen, 2014; Pondella II et al., 2008). GSB holds the highest trophic level of all coastal, bony fishes in most of its geographic distribution range.

Historically, GSB has been a valuable commercial and cultural resource on both sides of the U.S.-Mexico border. Before the collapse of its fishery in California, it was an important game fish that represented a significative economic resource (Domeier, 2001). In Mexico, GSB is still a traditionally important resource for commercial fishing communities, although there is little we know about its populations, its fishery, and there are no incentives to apply management strategies. This fish is also a charismatic and iconic species, as a recent study found that the economic value of recreational diving with GSB in California was US$2.3 million per year (Guerra et al., 2017).

Despite shared cultural and economic importance, the management of GSB across the U.S.-Mexico border is highly asymmetric. As a result of overfishing and a subsequent decline of the population, strong conservation regulations were imposed in the U.S. waters, whereas in Mexico regulations are almost non-existent (Allen, 2017; Domeier, 2001; Pondella & Allen, 2008). In 1981, a ban on commercial and recreational fishing was passed in the U.S. (Allen, 2017; Domeier, 2001; Pondella & Allen, 2008). This law granted the possibility of landing two GSB per trip to the U.S. commercial fishermen, and limited the U.S. capture in Mexican waters, allowing landings of up to 450 kg per trip and up to a maximum of 1,360 kg per year (CDFW 1981). This law was amended in 1988 to restrict to one fish per vessel if taken as bycatch and one fish per trip coming from Mexican waters. In 1990, the use of gillnets one nautical mile from the coast in southern California was banned. This regulation significantly reduced GSB bycatch in the southern California region (Pondella II et al., 2008).

In Mexico, the only GSB-specific existing regulation is for the recreational fishery, which allows a limit of one GSB per fishing permit per day (DOF 2013). Currently, the commercial fishery of GSB has no species-specific regulation. The National Fisheries Inventory (Carta Nacional Pesquera), which is the public management tool issued by the Federal Government, recommends not increasing the current fishing effort for any species under the category of "fin-fish fishery," a category that includes GSB (DOF 2012). However, GSB is not a targeted species by most of the Mexican fishermen cooperatives, the largest proportion of the catches are reported as bycatch of the white seabass and flatfish fishery. A very few fishers targeting GSB using hook-and-line or bottom-longline in the southern region of the Baja California peninsula. In addition to the regulation of recreational fishing in Mexico, it is speculated that the measures imposed by the U.S. that limited the number of GSBs caught in Mexican waters and landed in California also increased the protection of populations south of the border (Pondella II et al., 2008).

Thirty-eight years into the fishing ban in California, the U.S. stock continues to be well below historical levels (Baldwin and Keiser, 2008; Dayton et al., 1998; Ragen, 1990). The most recent assessment of effective population size was estimated to be less than 500 individuals (Chabot et al., 2015). Based on the few things that we do know about GSB biology demonstrates that it is a very vulnerable species to overfishing: it has slow growth rates, a late age-at-maturity, large size, and aggregates to spawn (Dulvy et al., 2003; Sadovy et al., 2020, 2013). These life-history traits may partially explain the slow population recovery despite several decades of protection. However, conservation efforts have generated some optimism in the recent recovery of California GSB populations. Signs of recovery include an increase in the number of larvae recorded over 15 years and an increased presence of GSB adults in fishery-independent surveys (House et al., 2016; Pondella II et al., 2008). However, the biomass calculated from the current populations in California still represents a much lower value than that existing before exploitation (Dayton and Maccall, 1990; Ragen, 1990). Two major conservation challenges exist: an incomplete knowledge of GSB life history, and a lack of understanding of how conservation measures imposed in the U.S. have impacted GSB populations in Mexican waters.

Nearly all that is known about GSBs life history and fishery comes from records and assessments of Californian populations (Allen, 2017; Baldwin and Keiser, 2008; Pondella II et al., 2008). Yet, almost three-quarters of the GSB distribution range is in Mexican waters, where historical records of fishery landings (commercial and recreational) suggest that a more abundant population existed (Baldwin and Keiser, 2008). Here, we discuss how the asymmetry in knowledge and management may represent a challenge for the conservation and sustainability of this critically endangered species. We aim to analyze: (a) variation in GSB scientific knowledge across the U.S.-Mexico border, (b) historical fishery trends of the U.S. fleet, (c) spatial patterns of the contemporary fishery from both the U.S. and Mexico, and (d) GSB population conservation threats across the U.S.-Mexico border. To address this, here we utilize historical fishery landings from the U.S. fleet, contemporary GSB landings in the U.S. and Mexico, and fishery-related biological monitoring data. This work represents the first joint analysis of the U.S.-Mexican GSB fishery, the first study to incorporate historical and contemporary perspectives of the GSB fishery, and the first study to our knowledge that addresses asymmetry in fishery management between the U.S. and Mexico.

## MATERIALS AND METHODS

The study encompasses the entire geographic distribution of the GSB in the Northeastern Pacific, ranging from Humboldt Bay, California (U.S.) to the Baja California peninsula and the Gulf of California (Mexico). However, adults are primarily found south of Point Conception and north of Bahía Magdalena (Love et al., 2005). Our data span more than 14 degrees of latitude (approximately 2,200 km) from Santa Cruz, California (37.6°N) to the southern range limit in the tip of the Baja California Peninsula (22.9°N), including the Gulf of California, Mexico.

### *a) Asymmetry in knowledge and research*

To evaluate existing knowledge and research, we collected all existing literature using ISI Web of Science and Google Scholar, using the following five words as search terms: "*Stereolepis gigas*" (exact match), "giant sea bass", "black sea bass", "mero gigante" (exact match), and "pescara" (Table 1). The latter two words are the official common names in Spanish (Page et al., 2013). In addition, we crosschecked the literature cited of all peer-reviewed articles focused on GSB. We downloaded all peer-reviewed papers for searches with up to 500 hits. We reviewed every downloaded paper to filter those that mention GSB as part of the references, or species list. The main topic of every paper, year of publication, and location of the populations studied were extracted from the papers. We summarize what is known about the GSB, its biology, and ecology, and include the reference to those papers.

To evaluate conservation and research efforts in economic investment, we compiled an exhaustive list of institutions and organizations involved in GSB initiatives in the U.S. and Mexico (Table 2). These institutions and organizations included research groups in academic institutions, NGOs, government agencies, aquariums, and independent specialists. We inquired information on the following areas: project locations, total investments, and time frames. Per year values of economic investment in research and conservation were obtained by dividing the total investment per country by the number of years the projects ran.

### *b) Asymmetry in Management*

### *Historical fishery trends*

GSB fishery landings data were obtained from two sources; Data previous of 2000 was extracted from published literature, and data from 2000 to 2016 was obtained from government agencies. 1) Data from 1913 to 1999, from the U.S. fleet, both commercial and recreational, were extracted from graphs on reports of the California Department of Fish and Wildlife (CDFW) using the program GraphClick v.3.0.3 (Arizona-Software, 2010). We collated historical data from both the U.S. commercial and recreational fleet in both the U.S. and Mexican waters. Data from the commercial fishery were converted to metric tons, while the data from the recreational fishery were reported in individuals.

2) Data from 2000-2016 was obtained from fishery government agencies. Mexican commercial fishery landings were obtained from the Mexican federal fishery agency (CONAPESCA, in its Spanish acronym). Commercial fishery landings in Mexico are obtained as fishing tickets, which includes catch site and date. The U.S. GSB fishery landings, both commercial and recreational, were obtained from the California Department Fish and Wildlife (CDFW). All GSB catches in the U.S. are recorded as bycatch, as fishers can report one GSB per fishery trip. All data were converted to metric tons and analyzed as the sum of annual catches.

### *Fishery and biological monitoring*

In March 2017 we established a biological monitoring program focused on obtaining data and samples from the GSB fishery in Mexican waters. We developed a collaborative network with fish markets, fisher cooperatives, NGOs, and government agencies. The monitoring program included fish-market surveys, records from fishing cooperatives, surveys in fishing communities, recreational fishery tournaments, fishery records shared over social media, and fishery-independent surveys. We developed a standardized species-specific protocol to obtain basic morphometric measurements and anatomical samples of GSB (Ramírez-Valdez et al., 2018). We measured total length (TL) (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg). The catch date, catch site, fishing gear, targeted species, and habitat were also recorded. One of the goals of this monitoring program was to describe the GSB catch composition in Mexican landings and the percentage of juvenile individuals of the total catch. The fish market surveys were carried out monthly from March to December 2017, afterward, we surveyed only after confirming the market had GSB. We measured every GSB in the fish market during our surveys, with the exception of a few cases when the total volume of GSB in the fish market exceeded 0.5 tons (typically more than 40 individuals). Although there is not yet a conclusive evidence on length at first maturity, the literature suggests that GSB reach maturity at 11 years and approximately 800 mm TL (Hawk and Allen, 2014).

We used the average tonnage of Mexican catches in the last 16 years and the average weight of the individuals evaluated in the biological monitoring to estimate the number of individual GSB removed each year in the Mexican fishery.

### *Spatial analysis of the fishery*

GSB fishery landings from 2000-2016 used for the spatial analysis come from the fishery trends in the previous section. Landings data were associated with spatial data to the finest scale possible. In the case of the U.S., we use the 10 × 10-minute grid constructed by CDFW, and for Mexico, we use the coastal fishing concession areas (Fig. 1). For areas where the fishing concession area was not available, we used Google Earth to obtain geographic data of the catch site. The vertices of the 10 × 10 minutes grid and fishing concession areas were obtained and digitalized in QGIS. We used the centroid of the polygons to visualize the catches. We used annual averages of the landings over the available data period (2000-2016) to identify the main contemporary GSB fishing grounds. We assumed each record in the database represented a separate a "fishing ticket," which we then used to evaluate relative catch-per-unit-effort and areas of higher capture frequency. The relationship between landings and fishing tickets were tested.

### *c) Asymmetry in the economic value*

We estimate the consumption and non-consumption value of the GSB across the border between the U.S. and Mexico. The consumption value was obtained using the commercial fishery landings data obtained from government agencies CDFW (U.S.) and CONAPESCA (Mexico) from 2000 to 2016. We use the fishing tickets to obtain the weight of catch and the official market price by kg. The annual value was obtained from the sum of the price market and then an annual average of 2000-2016 was obtained. The GSB official market price in Mexico was exchanged to dollars considering the annual average exchange rate.

The non-consumption value for the U.S. was obtained from the research published by Guerra et al. (2017). This work applied surveys to scuba divers who dive off the California coast and used the contingent valuation method to estimate the amount of money that divers are willing to pay for diving with GSB. A total of 265 scuba divers were interviewed in southern California from August to December 2015. The non-consumption value for Mexico was obtained from the total cost estimate of the only three expeditions that the authors are aware of have been organized to dive with GSB in Mexican waters. In Fall 2018, three expeditions of 9-14 scuba divers were organized to dive and photograph GSB in four sites of the Baja California peninsula, Mexico. We interviewed the fishing cooperatives that supported the fieldwork, and organizers of those expeditions and obtain the total coast associated to those diving trips.

## RESULTS

### *a) Asymmetry in knowledge and research*

Our systematic literature review identified a total of 49 scientific studies mentioning GSB, but only 26 included data on GSB populations (Table 1). From these 26 papers, 92% (n = 24) contained information on population status in California's waters, only three included data from both sides of the U.S.-Mexico border, and only two studies had information for the Mexican side only, however, neither study focused primarily on GSB (Table 1).

The literature reviewed revealed an increase in the number of publications on GSB since 2009, with 85% of all the GSB peer-reviewed papers being published in the past 10 years, suggesting that we are only now starting to learn about this already-threatened species. GSBs populations are the central topic of 17 (65%) of the total literature considered in this analysis (n = 26). Although the topics covered by this set of papers are diverse (e.g., age-growth analysis, genetic diversity, recruitment), research on the fishery and potential population sizes is notably absent. The only published literature on the history of the GSB fishery are technical reports from CDFW.

### *b) Asymmetry in Management*

#### *Historical fishery trends*

GSB fishery trends in the U.S, and Mexico show significant variability, with continuous peaks and dips since the first records of this fishery to the present day (Fig. 2). Historical evidence indicates that commercial fishing of GSB in the U.S. began in 1870, while recreational fishing began in 1895. The fish were first targeted with set lines and hand lines (Status Fisheries Report 2008). The history of the GSB fishery can be described in five clear periods, marked by development of the fishery and policy interventions; a) the development of the GSB fishery, b) the collapse of the fishery in the U.S. waters, c) the development of the GSB fishery in Mexican waters, d) the collapse of the U.S. landings from Mexican waters, and e) the contemporary fishery, from 2000-2016.

In the first period (before 1923), represents the development of the GSB fishery in CA, where the U.S. fleet fished mostly in local waters, supplemented by a small portion of landings coming from Mexican waters. In the second period (from 1923 to 1931), the U.S. fleet increased landings from local waters until a maximum of 111 ton/yr in 1929, while the U.S. commercial landings from Mexican waters began rapidly increasing until catches from Mexican waters exceeded catches in the U.S. waters. During the third period (from 1932 to 1945), the U.S. fishery dramatically shifted to being entirely a foreign-waters fishery. The local landings from the U.S. fleet collapsed to virtually nothing and remained below 10 ton/yr for the following 20 years, while fleet landings in Mexican waters increased to 386 tons and averaged 220 tons annually during the entire period (Fig. 3). At the end of this period, a sharp decline in landings coming from Mexico was observed, apparently due to the U.S. entering World War II, an effect observed in most fisheries in California (i.e., white sea bass, Pacific halibut, Dungeness crab) (CDFW 2014). The absence of historical fishing statistics for the Mexican fleet does not allow us to know the exact volume of catches; however, we know that at this point GSB fishery by Mexican fleet was present to some degree, such that in 1933 the California Fisheries Yearbook mentioned: “a considerable part of the [GSB] catch consists of fish caught in Mexican waters”, “most of this amount is taken by California fishermen off the west coast of Lower California, but a few pounds are caught by Mexicans in the Gulf of California and shipped to Los Angeles by refrigerated trucks as a side issue to the totoaba fishery." (CDFW 1935).

The fourth period (from 1946 to 1999) was marked by collapse of the U.S. commercial fishery in Mexican waters when catches fell from 152 tons in 1964 to 14 tons in 1972. This period also coincides with the development of the Mexican fishery in the Baja California Peninsula, in the late 1950s when the first fishing cooperatives were founded. Evidence suggests that following fast growth by the Mexican commercial fishery in Baja, a rapid decline was evident in grouper populations in the early 1960s (Saenz-Arroyo et al., 2005). Fishery landings for the Baja California Peninsula show that by 1980 the cluster "groupers and cabrillas", which includes GSB, averaged 400 ton per year (DOF 2014).-In the 1990s catches increased to reach an average of 6,000 tons. The development of the recreational fishery by the U.S. fleet is notable during in this period (Fig. 2B). The U.S. recreational fishery reached its maximum in local waters in 1963 (500 ind/yr) and seven years later collapsed (50 ind/yr); while in Mexican waters, this fishery increased over the same period, from 100 ind/yr in 1963 to 800 ind/yr in 1971 before declining in 1980 (Fig. 2B). In 1982, the GSB fishery was entirely closed for the U.S. commercial fleet, which by then were recording <2 ton/yr in U.S. waters. In 1994 a ban for the use of gillnets was declared off the southern California coast (Fig. 2A). Thereafter, GSB landings in the U.S. waters were a result of bycatch.

The fishery landings from the U.S. recreational fleet in local and Mexican waters shows a staggered pattern of decrease and increase (Fig. 3). First, the collapse of the GSB commercial fishery in the U.S. waters marked the rise in catches by the U.S. fleet in Mexican waters. More than 40 years later, the collapse of GSB fishery by the U.S. commercial fleet in Mexican waters coincides with a marked increase in landings by the U.S. recreational fleet from south of the U.S.-Mexico border. The first peak in the GSB landings by the U.S. recreational fishery was recorded in 1967 with more than 600 ind/yr; three years later, this fishery reached its maximum with approximately 770 ind/yr. The U.S. recreational fishery in Mexican waters continued fluctuating for the following 10 years, averaging 315 ind/yr. In 1982, both the fisheries collapsed.

The fifth period corresponds to what we call here as the contemporary fishery (from 2000 to 2016). This is the period where the fishery statistics begin by the Mexican government and also when some of the most important fisheries management regulations and policies began.

### ***Spatial analysis of the fishery***

Records for the GSB Mexican commercial fishery landings began in 2000 (Fig. 4). Average landings were 50.9± 16.6 SD ton/yr during the period of 2000-2016 and represent a third of what the U.S. commercial fishery reported until the fishery collapsed in 1932. Landings by the Mexican commercial fleet showed two peaks, the first in 2010 reaching 78.8 ton/yr, the second in 2015 with 102 ton/yr. However, overall, GSB catches in Mexico have never dropped below 33 tons/yr in the past 16 years. Fisheries landings parallel species distribution, and are widely distributed from Monterey Bay, CA, to the tip of the Baja California Peninsula and inside the Gulf of California. The highest landings were in the region south of Sebastian Viscaino (28.5°N), and north of Bahía Magdalena, Mexico (24.3°N). Isla de Cedros, Laguna de San Ignacio, San Juanico, and Bahía Magdalena are especially productive fishing grounds that collectively average more than 4 ton/yr. The highest landings in the Gulf of California occur in the northern region, although Santa Rosalia, in the central region, has reported more GSB catches (“fishing tickets”) over time. In the U.S., landings have been concentrated near San Diego, Dana Point, San Pedro, and Santa Barbara, California, though the Channel Islands and the U.S.-Mexico border also have a high number of landings.

Over 36 months (2017-2020) of monitoring, we accumulated 209 records of individual organisms being caught: 112 came from fish market surveys, 53 from fishing cooperatives, 9 from fishing tournaments, and 35 from other sources (e.g. social media records, fish collections, fishery-independent surveys) (Table 2, Fig. 5). Total lengths observed spanned the maximum size distribution for the species, and fish were captured using all known fishing methods. Records cover most of the distribution range of this species in Mexican waters, with a higher proportion of records from the region with higher landings in Mexico (Fig. 4). 74% of the records come from surveys in fish markets from Ensenada and Tijuana, Mexico. Those markets are the main sale centers for all fisheries in the Baja California Peninsula. GSB sold in these markets are brought from numerous fishing grounds in the region. The records from fishing cooperatives and fishing tournaments represent a lower percentage (36%); however, they represent valuable information as individuals are typically larger and fishers reported precise geographic information on the site of capture. The size distribution showed a normal distribution, from 300-2000 mm TL mm (Figure 5, Table 2).; 48.4% of the records were <800 mm TL, indicating a large number of potential juveniles. The average weight of individuals was 25 kg.

Using the average tonnage of catches (50 ± 35 SD ton/yr) and the average weight of individuals (25 kg), We calculate that the number of individuals removed annually by the Mexican fishery could be approximately 2080 ind/yr. Additionally, some 90 individuals may come from the 3 ± 21 SD Ton/yr result of by-catch in the U.S. waters. must still be added to obtain the total GSB removed yearly.

# DISCUSSION

Our research reveals a broad asymmetry in the scientific knowledge, research, management, and economic value of giant sea bass (GSB) across the U.S.-Mexico political border (Fig. 8). This asymmetry generates a complex scenario for fishery management and hinders conservation efforts. We argue that the broad differences in current scientific knowledge and management may be the main barrier to achieving a sustainable fishery in the U.S., and in this case, the population recovery of an endangered species. The management of shared fishery stocks can be complex and a matter of international controversy (e.g. cod war between England and Iceland, the lobster war between France and Brazil) yet, little progress in developing strategies that provide long-term certainty have been made (Bowett, 1968; Mirvahabi, 1978; Steinsson, 2016). Shared fishery stocks are more prone to overexploitation compared to solely-owned stocks as they experience additional complexity in their management, and a lack of cooperation that can lead to a version of the "tragedy of the commons" between nations (McWhinnie, 2009). Asymmetry in resource management across political borders should not be seen as a barrier to binational cooperation but should be considered in the development of fishery policies.

This work represents the first synthesis of knowledge of the GSB fishery across the U.S.-Mexico border, the first to analyze existing historical fishery data and the contemporary landings, and the first effort to discuss the asymmetry in fishery management between the U.S. and Mexico. For a long time, the need to analyze the historical landings, and to lead efforts to interpret landings trends was perceived as unnecessary, because the U.S. GSB fishery was closed 38 years ago, and populations were depleted in local waters 88 years ago. In Mexico, despite the fact that there is an ongoing fishery, the fisheries sector and the government assign little relevance to this resource as it is not a target fishery. These may be the same reasons why the U.S. and Mexico governments have shown little interest in addressing this shared resource cooperatively, analyzing transboundary catch trends, or unifying the general public perception of the status of this species.

### a) Asymmetry in knowledge and research

In this study, we found that extremely strong asymmetry exists in scientific knowledge, economic input, and conservation initiatives across the U.S.-Mexico border; that political regulations not only hid historical population collapses but also created the illusion of false ones. Asymmetry in the scientific knowledge may impact the perception of the health of the GSB population for fishers and fishery managers by having incomplete information or data and hinder the willingness to cooperate in transboundary science-based management (Miller and Munro, 2002; Munro, 2018; Vosooghi, 2019). Despite the fact that more than 70% of the GSB geographic distribution is south of the U.S.-Mexico border, there are up to 5x more scientific papers on the U.S. populations. Finding this difference in knowledge in this political border region with marked socioeconomic differences may not be surprising. These differences in knowledge are not exclusive of GSB, and have been observed for other species of fishes (Ishimura et al., 2013b). However, here we show that developing scientific knowledge of shared natural resources appears to be limited by the political border, as we found only three peer-reviewed papers include data on populations on both sides of the U.S.-Mexico border. The scientific community has highlighted the need for a transboundary perspective when developing research and management of natural resources, yet many political and administrative barriers to achieving this goal persist, which may explain the scarce number of papers with that approach (Aburto-Oropeza et al., 2018). One of the first challenges would be to generate synergy to discuss and address cross-border issues between government agencies, within countries and between countries, the U.S., and Mexico. Government fishery agencies, together with other government agencies (i.e., Tourism, Economy), agencies should create working groups to coordinate data sharing, launch collaborative programs, and in general, address cross-border issues in coordination. These working groups would not only facilitate the identification of priority topics, but homogenization of management regulations, granting research permits, and promoting economic activities. Governments should support programs to incentivize cross-border research, generate capacity building, offer technical training, and support the creation of specialists on transborder resources management.

### b) Asymmetry in the management

Our analysis of the historical landings of the GSB reveals a new narrative in the history of this fishery, showing that the collapse of the GSB populations in the U.S. waters occurred much earlier than previously thought, and that the decline of GSB landings by the U.S. fleet in Mexican waters may be the result of binational regulation of the commercial fishery rather than a population collapse.

The U.S. fleet fishery landings in Mexican waters masked the reality of the collapse of populations north of the border for over 40 years (Fig. 2A). Only in 1981 was the moratorium of the GSB fishery made official, 50 years after the fishery collapsed in local the U.S. waters. The reason for postponing the regulation of this fishery is uncertain; however, it is fair to argue that ban fishing in the U.S. waters long before could have made it difficult the regulate the fishery landings coming from Mexican waters, and possible, also the negotiations with Mexico to continue fishing in its waters.

The apparent collapse of GSB landings south of the border in 1972 may be an effect of a binational treaty on fisheries management. In 1967, and previous to Mexico EEZ declaration, both countries, the U.S. and Mexico, signed an agreement in which they recognized their exclusive jurisdiction for fishing purposes of their territorial sea (International Legal Materials, 1968). Under this agreement, the U.S. was granted a period of five years to fish GSB (and many other species) in Mexican waters up to a total volume that could not exceed the Mexican fleet catch of that species. The end of the granted period coincides with the "collapse" of the U.S. GSB fishery in Mexican waters in 1972. However, these regulations focused exclusively on the commercial fishery, which explains why high catches of Mexican fish in the U.S. recreational fishery continued. In 1976, Mexico officially declared its EEZ, which regulated both commercial and recreation fishing fleets from foreign countries.

Contemporary fishing landings (2000-2016) show the asymmetry in the current management of this species across the political border. Combined fishery landings in Mexico represent less than 12% of the historic peak of 450 tons recorded by the U.S. fleet prior to its collapse in 1932. Our contemporary fishery landings analysis highlights three major findings: a) high annual variability in catches, b) location of main fishing grounds in southern Baja California, and c) the population size of this species across its entire distribution range is likely higher than previously thought.

The fluctuation of the Mexican commercial fishery annual catches is similar to historical trends, and also is similar to what has been reported for other long-lived and aggregate spawning fish (Erisman et al., 2010; Sadovy de Mitcheson et al., 2013). In general, fishery landings fluctuations may be the result of the natural variability of the population due to changes in predation and recruitment, climatic variability, and/or changes in fishing effort (Roughgarden and

Smith, 1996). Since 2005, the fishing concessions and commercial fishery permits in the region have remained steady, as has the number of boats that each operates; however, they can increase the number of fishing trips (SEPESCA, 2018). Our analysis shows that the fluctuation in the contemporary landings of the Mexican commercial fleet is highly correlated to the fishing effort (fishing tickets). Also, an increase in GSB fishing effort is correlated to a decrease in fishing production from other higher-valuable fishing resources (i.e. lobster, sea urchin). Although the GSB is not a target fishery in most of the Baja California Peninsula fishing grounds, members of fishing cooperatives with permits for a variety of species could shift to fishing GSB when other resources decline. The largest proportion of GSB landings is reported in summer, during the finfish fishery season (i.e. white seabass, flatfish) which also coincides with the seasonal ban of the highest value fisheries in the region (i.e. lobster, abalone, sea urchin) (SEPESCA, 2018). The fishing pressure upon GSB populations may increase as a result of the decline of other fisheries as it is considered an alternative resource.

Contemporary landings clearly show the asymmetry in the current management of the GSB fishery, averaging 53 tons per year, where 94% comes from Mexican waters. Some of the most productive fishing grounds (i.e., Vizcaíno, Isla Cedros, Punta Abreojos, Bahia Tortugas, Ojo de Liebre) have average catches of up to 6 tons per year, and their high productivity is also observed in other fisheries (i.e., lobster, abalone, barred sand bass, yellowtail) (Micheli et al., 2014; Nishigaki et al., 2014). In the 1970s, the U.S. recreational fishing fleet recorded fishing trips to these same fishing grounds caught on average 70-100 individuals consistently, sometimes up to 255 individuals on a three-day trip (Domeier, 2001). Contemporary catches extend throughout the geographic distribution range reported for the GSB, ruling out that entire populations have been extirpated as a result of overfishing.

Our analysis from biological monitoring in the Mexican fleet allows us to estimate that the GSB population size could be larger than we previously thought. The total catch from the U.S. and Mexican waters combined of more than 53 tons per year could represent up to 2,120 GSB individuals per year. Considering that up to 48.4% of the GSB sampled by the Mexican commercial fishery are juvenile individuals, the adults removed annually could be up to 1,026 individuals. Chabot, Hawk, & Allen, (2015) estimated the effective population size of 500 GSB including samples from California and Mexico, adding that this could be approximately 10% of the census population size. Fish species with the characteristics of GSB (i.e., long lifespans, long generation times, and lower fecundity), the ratio between the effective population size and the census population size could be lower (e.g., the census population is closer to the estimated effective population size). Low effective population sizes may be the result of small total population size, strongly fluctuating population sizes, the existence of a bottleneck process in the population, unequal sex ratio, and variance in family size (Shrimpton and Heath, 2003). Several of them could be plausible scenarios in the GSB population. Therefore, it is necessary to incorporate more population parameters to obtain a better estimate of the population size for this species.

### c) Binational cooperation and thinking ahead

We see with concern that most of the scientific work that addresses shared fish stocks coincide in pointing out that binational cooperation in research and species management is the only long-term promising strategy. Since 1970s studies have pointed out the need for a transborder perspective in management, and since then numerous studies have added study cases and scenarios (Munro, 2018). Some success stories can provide a framework, such as the Pacific sardine, where the key has been multilateral agreements signed between the U.S. and Mexico (Cisneros-Montemayor et al., 2020). However, transboundary management has not occurred for GSB, nor for most other fishery species, including lobster, abalone, sharks, and white seabass fisheries (Holts et al., 1998; Munguia-Vega et al., 2014; Romo-Curiel et al., 2016). The lack of cooperation appears to be driven by uneven knowledge and research and the economic and cultural dominance of the U.S. (Miller and Munro, 2004). Although there is a long list of attempts towards transboundary management attempts in natural resources between Mexico and the U.S., there are just a few success stories. To be successful, both parties involved must benefit economically as a result of the cooperation. Unlike tuna or sardine, CDFW and CONAPESCA do not place the same priority on GSB. Compared with other species, the economic value of the GSB is negligible. Despite the scientific evidence and popular knowledge of the large economy associated with GSB tourism, the disconnect between government agencies (i.e., fishery and tourism agencies) makes it difficult for further international cooperation to promote a shift in resource use.

The information provided by this study may open the opportunity to discuss binational agreements in the management of this (and other) marine resource. The current vision in the fisheries of share stocks on responsible management within the EEZ has proven to be insufficient. In most cases, the tragedy of the commons is apparent (McWhinnie, 2009). This adverse scenario will be exacerbated as fish stocks shift as a consequence of climate change and the graduate tropicalization of temperate ocean systems (Lluch Cota et al., 2017; Vergés et al., 2014). A possible future scenario could see both countries with an equal proportion of the GSB population. However, sustainable stocks in this scenario will not be likely without setting the foundations for binational management. It is in the best interests of both parties to recover the population of the GSB, not only from the fishing point of view but for its ecological role and cultural value.

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# REFERENCES

Aburto-Oropeza, O., Johnson, A.F., Agha, M., Allen, E.B., Allen, M.F., González, J.A., Arenas Moreno, D.M., Beas-Luna, R., Butterfield, S., Caetano, G., Caselle, J.E., Gaytán, G.C., Castorani, M.C.N., Cat, L.A., Cavanaugh, K., Chambers, J.Q., Cooper, R.D., Arafeh-Dalmau, N., Dawson, T., de la Vega Pérez, A.D., DiMento, J.F.C., Guerrero, S.D., Edwards, M., Ennen, J.R., Estrada-Medina, H., Fierro-Estrada, N., Gadsden, H., Galina-Tessaro, P., Gibbons, P.M., Goode, E. V., Gorris, M.E., Harmon, T., Hecht, S., Heredia Fragoso, M.A., Hernández-Solano, A., Hernández-Cortés, D., Hernández-Carmona, G., Hillard, S., Huey, R.B., Hufford, M.B., Jenerette, G.D., Jiménez-Osornio, J., López-Nava, K.J., Lara Reséndiz, R.A., Leslie, H.M., López-Feldman, A., Luja, V.H., Méndez, N.M., Mautz, W.J., Medellín-Azuara, J., Meléndez-Torres, C., de la Cruz, F.R.M., Micheli, F., Miles, D.B., Montagner, G., Montaño-Moctezuma, G., Müller, J., Oliva, P., Ortinez Álvarez, J.A., Ortiz-Partida, J.P., Palleiro-Nayar, J., Páramo Figueroa, V.H., Parnell, P.E., Raimondi, P., Ramírez-Valdez, A., Randerson, J.T., Reed, D.C., Riquelme, M., Torres, T.R., Rosen, P.C., Ross-Ibarra, J., Sánchez-Cordero, V., Sandoval-Solis, S., Santos, J.C., Sawers, R., Sinervo, B., Sites, J.W., Sosa-Nishizaki, O., Stanton, T., Stapp, J.R., Stewart, J.A.E., Torre, J., Torres-Moye, G., Treseder, K.K., Valdez-Villavicencio, J., Valle Jiménez, F.I., Vaughn, M., Welton, L., Westphal, M.F., Woolrich-Piña, G., Yunez-Naude, A., Zertuche-González, J.A., Taylor, J.E., 2018. Harnessing cross-border resources to confront climate change. Environ. Sci. Policy 87, 128–132. https://doi.org/10.1016/j.envsci.2018.01.001

Allen, L.G., 2017. GIANTS! Or…The Return of the Kelp Forest King. Copeia 105, 10–13. https://doi.org/10.1643/CI-17-577

Baja California State Government, 2017. Carta Estatal Pesquera de Baja California 2000-2018. https://doi.org/10.1017/CBO9781107415324.004

Baldwin, D.S., Keiser, A., 2008. Giant Sea Bass, Stereolepis gigas. Status of the fisheries. Report California Department of Fish and Game. California.

Block, B.A., Jonsen, I.D., Jorgensen, S.J., Winship, A.J., Shaffer, S.A., Bograd, S.J., Hazen, E.L., Foley, D.G., Breed, G.A., Harrison, A.L., Ganong, J.E., Swithenbank, A., Castleton, M., Dewar, H., Mate, B.R., Shillinger, G.L., Schaefer, K.M., Benson, S.R., Weise, M.J., Henry, R.W., Costa, D.P., 2011. Tracking apex marine predator movements in a dynamic ocean. Nature 475, 86–90. https://doi.org/10.1038/nature10082

Bowett, D.W., 1968. The Law of the Sea, Netherlands International Law Review. Manchester University Press, Oceana Publications Inc. https://doi.org/10.1017/s0165070x00025626

Caddy, J.F., 1997. Establishing a consultative mechanism or arrangement for managing shared stocks within the jurisdiction of contiguous states, in: Taking Stock: Defining and Managing Shared Resources. Australian Society for Fish Biology and Aquatic Resource Management

Association of Australasia Joint Workshop Proceedings, p. 16.

Cavole, L.M., Demko, A.M., Diner, R.E., Giddings, A., Koester, I., Pagniello, C.M.L.S., Paulsen, M.-L., Ramirez-Valdez, A., Schwenck, S.M., Yen, N.K., Zill, M.E., Franks, P.J.S., 2016. Biological impacts of the 2013–2015 warm-water anomaly in the northeast Pacific: Winners, Losers, and the Future. Oceanography 29. https://doi.org/10.5670/oceanog.2016.32

Chabot, C.L., Hawk, H.A., Allen, L.G., 2015. Low contemporary effective population size detected in the Critically Endangered giant sea bass, Stereolepis gigas, due to fisheries overexploitation. Fish. Res. 172, 71–78. https://doi.org/10.1016/j.fishres.2015.06.015

Cisneros-Montemayor, A.M., Cisneros-Mata, M.A., Harper, S., Pauly, D., 2013. Extent and implications of IUU catch in Mexico's marine fisheries. Mar. Policy 39, 283–288. https://doi.org/10.1016/j.marpol.2012.12.003

Cisneros-Montemayor, A.M., Ishimura, G., Munro, G.R., Sumaila, U.R., 2020. Ecosystem-based management can contribute to cooperation in transboundary fisheries: The case of pacific sardine. Fish. Res. 221. https://doi.org/10.1016/j.fishres.2019.105401

Cornish, A., 2004. Stereolepis gigas, Giant Sea Bass. IUCN Red List Threat. Species 8235.

Dayton, P.K., Maccall, A.D., 1990. Pre-exploitation abundances of important large recreational and commercial fishes off Southern California. Calif. Sea Grant, Bienn. Rep. Complet. Proj. 1988-90 1884, 91–96.

Dayton, P.K., Tegner, M.J., Edwards, P.B., Riser, K.L., 1998. Sliding baselines, ghosts, and reduced expectations in kelp forest communities. Ecol. Appl. 8, 309–322. https://doi.org/10.1890/1051-0761(1998)008[0309:SBGARE]2.0.CO;2

Domeier, M., 2001. Giant Sea Bass. California's Mar. Living Resour. A Status Rep. 209–211.

Dulvy, N.K., Sadovy, Y., Reynolds, J.D., 2003. Extinction vulnerability in marine populations. Fish Fish. 4, 25–64. https://doi.org/10.1046/j.1467-2979.2003.00105.x

Erisman, B., Mascarenas, I., Paredes, G., Sadovy, Y., Aburto-Oropeza, O., Hastings, P., 2010. Seasonal, annual, and long-term trends in commercial fisheries for aggregating reef fishes in the Gulf of California, Mexico. Fish. Res. 106, 279–288. https://doi.org/10.1016/j.fishres.2010.08.007

Erisman, B.E., Allen, L.G.L., Claisse, J.J.T., Pondella, D.J., Miller, E.F., Murray, J.H., Pondella II, D.J., Miller, E.F., Murray, J.H., 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Can. J. Fish. Aquat. Sci. 68, 1705–1716. https://doi.org/10.1139/f2011-090

Free, C.M., Mangin, T., Molinos, J.G., Ojea, E., Burden, M., Costello, C., Gaines, S.D., 2020. Realistic fisheries management reforms could mitigate the impacts of climate change in most countries. PLoS One 15, 1–21. https://doi.org/10.1371/journal.pone.0224347

Gaines, S.D., Costello, C., Owashi, B., Mangin, T., Bone, J., Molinos, J.G., Burden, M., Dennis, H., Halpern, B.S., Kappel, C. V., Kleisner, K.M., Ovando, D., 2018. Improved fisheries management could offset many negative effects of climate change. Sci. Adv. 4, 1–8. https://doi.org/10.1126/sciadv.aao1378

Ganster, P., 2009. Sustainable Development and the U.S.-Mexico Border Region. Public Adm. Rev. 69, 153–155. https://doi.org/10.1111/j.1540-6210.2008.01957.x

Guerra, A.S., Madigan, D.J., Love, M.S., Mccauley, D.J., 2017. The worth of giants: The consumptive and non-consumptive use value of the giant sea bass (Stereolepis gigas). Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 1–9. https://doi.org/10.1002/aqc.2837

Hawk, H.A., Allen, L.G., 2014. AGE AND GROWTH OF THE GIANT SEA BASS, STEREOLEPIS GIGAS. Calif. Coop. Ocean. Fish. Investig. REPORTS 55, 128–134.

Holts, D.B., Julian, A., Sosa-Nishizaki, O., Bartoo, N.W., 1998. Pelagic shark fisheries along the west coast of the United States and Baja California, Mexico. Fish. Res. 39, 115–125. https://doi.org/10.1016/S0165-7836(98)00178-7

Horn, M., Allen, L.G., Lea, R.N., 2006. Biogeography, in: The Ecology of Marine Fishes: California and Adjacent Waters.

House, P.H.P.H.P.H., Clark, B.L.F.B.L., Allen, L.G., Allen, Larry G, 2016. The Return of the King of the Kelp Forest : Distribution , Abundance , and Biomass of Giant Sea Bass ( Stereolepis gigas ) off Santa Catalina Island , California , 2014-2015. BioOne 115, 1–14. https://doi.org/10.3160/soca-115-01-1-14.1

International Legal Materials (Ed.), 1968. Mexico and United States: Fisheries Agreement. American Society of International Law, pp. 312–319.

Ishimura, G., Herrick, S., Sumaila, U.R., 2013a. Fishing games under climate variability: Transboundary management of Pacific sardine in the California Current System. Environ. Econ. Policy Stud. 15, 189–209. https://doi.org/10.1007/s10018-012-0048-0

Ishimura, G., Herrick, S., Sumaila, U.R., 2013b. Stability of cooperative management of the Pacific sardine fishery under climate variability. Mar. Policy 39, 333–340. https://doi.org/10.1016/j.marpol.2012.12.008

Leet, W.S., Dewees, C.M., Klingbeil, R., Larson, E.J., 2001. California's Living Marine Resources: A Status Report, California Department of Fish and Game. University of California Press, Davis, CA.

Lluch Cota, S., Salvadeo, C., Lluch Cota, D., Saldivar-Lucio, R., Ponce-Díaz, G., 2017. Impacts of Climate Change on Mexican Pacific Fisheries, in: Phillips, B.F., Perez-Ramirez, M. (Eds.), Climate Change Impacts on Fisheries and Aquaculture: A Global Analysis. Wiley Blackwell, West Sussex, UK, pp. 219–238.

Love, M.S., 2012. Certainly More Than You Want to Know About The Fishes of The Pacific

Coast—A Postmodern Experience. Really Big Press, Santa Barbara.

Love, M.S., Mecklenburg, C.W., Meclenburg, A.T., Thorsteinson, L.K., 2005. Resource Inventory of marine and estuarine Fishes of the West Coast and Alaska. U.S Geological Survey. https://doi.org/10.3133/70179564

McWhinnie, S.F., 2009. The tragedy of the commons in international fisheries: An empirical examination. J. Environ. Econ. Manage. 57, 321–333. https://doi.org/10.1016/j.jeem.2008.07.008

Micheli, F., De Leo, G., Butner, C., Martone, R.G., Shester, G., 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries. Biol. Conserv. 176, 224–235. https://doi.org/10.1016/j.biocon.2014.05.031

Miller, K.A., Munro, G., 2002. Cooperation and conflict in the management of transboundary fishery resources. Second World Congr. Am. Eur. Assoc. Environ. Resour. Econ. Monterey, Calif.

Miller, K.A., Munro, G.R., 2004. Climate and cooperation: A new perspective on the management of shared fish stocks. Mar. Resour. Econ. 19, 367–393. https://doi.org/10.1086/mre.19.3.42629440

Mirvahabi, F., 1978. Significant Fishery Management Issues in the Law of the Sea Conference: Illusions and Realities. San Diego Law Rev. 15, 493.

Munguia-Vega, A., Jackson, A., Marinone, S.G., Erisman, B., Moreno-Baez, M., Girón-Nava, A., Pfister, T., Aburto-Oropeza, O., Torre, J., 2014. Asymmetric connectivity of spawning aggregations of a commercially important marine fish using a multidisciplinary approach. PeerJ 2, e511. https://doi.org/10.7717/peerj.511

Munro, G.R., 2018. The Optimal Management of Transboundary Renewable Resources. Can. J. Econ. / Rev. Can. d'Economique 12, 355–376.

Nishigaki, T., Jose, O., Laura Gonzalez-Cota, A., Romero, F., Trevino, C.L., Darszon, A., 2014. Intracellular pH in sperm physiology. Biochem. Biophys. Res. Commun. 450, 1149–1158. https://doi.org/10.1016/j.bbrc.2014.05.100

Page, L.M., Espinosa-Perez, H., Findley, L.T., Gilbert, C.R., Lea, R.N., Mandrak, N.E., Mayden, R.L., Nelson, J.S., 2013. Common and Scientific Names of Fishes from the United States, Canada, and Mexico, Common and Scientific Names of Fishes from the United States, Canada, and Mexico. American Fisheries Society, Bethesda, MD.

Paterson, C.N., Chabot, C.L., Robertson, J.M., Erisman, B., Cota-Nieto, J.J., Allen, L.G., 2015. The genetic diversity and population structure of barred sand bass, Paralabrax nebulifer: A historically important fisheries species off southern and Baja California. Calif. Coop. Ocean. Fish. Investig. Reports 56, 1–13.

Pinsky, M.L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., Cheung, W.W.L.,

2018. Preparing ocean governance for species on the move. Science (80-. ). 360, 1189–1191. https://doi.org/10.1126/science.aat2360

Pondella II, D.J., Allen, L.G., Pondella, D.J., Allen, L.G., 2008. The decline and recovery of four predatory fishes from the Southern California Bight. Mar. Biol. 154, 307–313. https://doi.org/10.1007/s00227-008-0924-0

Ragen, T., 1990. The estimation of theoretical population levels for natural populations.

Ramírez-Valdez, A., Sgarlatta, M.P., Villaseñor-Derbez, J., Cota-Nieto, J., Rowell, T., Gomez-Gomez, A., Dominguez-Guerrero, I., Dominguez-Reza, R., Hernández-Velasco, A., Santana-Morales, O., Ruiz-Campos, G., Erisman, B., 2018. Manual para el monitoreo biológico del mero gigante (Stereolepis gigas) en aguas mexicanas. Mexico City.

Romo-Curiel, A.E., Herzka, S.Z., Sepulveda, C.A., Pérez-Brunius, P., Aalbers, S.A., 2016. Rearing conditions and habitat use of white seabass (Atractoscion nobilis) in the northeastern Pacific based on otolith isotopic composition. Estuar. Coast. Shelf Sci. 170, 134–144. https://doi.org/10.1016/j.ecss.2016.01.016

Roughgarden, J., Smith, F., 1996. Why fisheries collapse and what to do about it. Proc. Natl. Acad. Sci. U. S. A. 93, 5078–5083. https://doi.org/10.1073/pnas.93.10.5078

Sadovy, Y., Craig, M.T., Bertoncini, A.A., Carpenter, K.E., Cheung, W.W.L., Choat, J.H., Cornish, A.S., Fennessy, S.T., Ferreira, B.P., Heemstra, P.C., Liu, M., Myers, R.F., Pollard, D.A., Rhodes, K.L., Rocha, L.A., Russell, B.C., Samoilys, M.A., Sanciangco, J., 2013. Fishing groupers towards extinction: A global assessment of threats and extinction risks in a billion dollar fishery. Fish Fish. 14, 119–136. https://doi.org/10.1111/j.1467-2979.2011.00455.x

Sadovy, Y., Linardich, C., Barreiros, J.P., Ralph, G.M., Aguilar-Perera, A., Afonso, P., Erisman, B.E., Pollard, D.A., Fennessy, S.T., Bertoncini, A.A., Nair, R.J., Rhodes, K.L., Francour, P., Brulé, T., Samoilys, M.A., Ferreira, B.P., Craig, M.T., 2020. Valuable but vulnerable: Over-fishing and under-management continue to threaten groupers so what now? Mar. Policy 116. https://doi.org/10.1016/j.marpol.2020.103909

Saenz-Arroyo, A., Sáenz-Arroyo, A., Roberts, C.M., Torre, J., Cariño-Olvera, M., Enríquez-Andrade, R.R., 2005. Rapidly shifting environmental baselines among fishers of the Gulf of California. … R. … 272, 1957–1962. https://doi.org/10.1098/rspb.2005.3175

Selkoe, K., Vogel, A., Gaines, S., 2007. Effects of ephemeral circulation on recruitment and connectivity of nearshore fish populations spanning Southern and Baja California. … Ecol. Ser. … 351, 209–220.

Shaw, M.R., Pendleton, L., Cameron, D.R., Morris, B., Bachelet, D., Klausmeyer, K., Mackenzie, J., Conklin, D.R., Bratman, G.N., Lenihan, J., Haunreiter, E., Daly, C., Roehrdanz, P.R., 2011. The impact of climate change on California ' s ecosystem services 109, 465–484. https://doi.org/10.1007/s10584-011-0313-4

Shrimpton, J.M., Heath, D.D., 2003. Census vs. effective population size in chinook salmon: large-and small-scale environmental perturbation effects. Mol. Ecol. 12, 2571–2583. https://doi.org/10.1046/j.1365-294X.2003.01932.x

Steinsson, S., 2016. The Cod Wars: a re-analysis. Eur. Secur. 25, 256–275. https://doi.org/10.1080/09662839.2016.1160376

Tegner, M.J., Dayton, P.K., 2000. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

Vergés, A., Steinberg, P.D., Hay, M.E., Poore, A.G.B., Campbell, A.H., Ballesteros, E., Heck, K.L., Booth, D.J., Coleman, M.A., Feary, D.A., Figueira, W., Langlois, T., Marzinelli, E.M., Mizerek, T., Mumby, P.J., Nakamura, Y., Roughan, M., van Sebille, E., Gupta, A. Sen, Smale, D.A., Tomas, F., Wernberg, T., Wilson, S.K., 2014. The tropicalization of temperate marine ecosystems : climate-mediated changes in herbivory and community phase shifts The tropicalization of temperate marine ecosystems : climate-mediated changes in herbivory and community phase shifts. Proc. R. Soc. B Biol. Sci. 281, 1–10. https://doi.org/10.1098/rspb.2014.0846

Vosooghi, S., 2019. Panic-Based Overfishing in Transboundary Fisheries. Environ. Resour. Econ. 73, 1287–1313. https://doi.org/10.1007/s10640-018-0299-8

# TABLES

Table 2.1.1. Scientific knowledge on GSB in peer-reviewed papers. WS= ISI Web of Science; GS= Google Scholar. GSB-listed= Papers that mention GSB. GSB-centric Paper= Papers that are focused on GSB.

| **Key-words** | **Search Engine** | **Hits** | **GSB-listed** | **Cummulative** |
|---|---|---|---|---|
| "*Stereolepis gigas*" | WS | 14 | 14 | 14 |
| | GS | 420 | 47 | 47 |
| giant sea bass | WS | 14 | 14 | 47 |
| | GS | 386 | 22 | 48 |
| black sea bass | WS | 189 | 1 | 49 |
| | GS | 5230 | 0 | |
| "mero gigante" | WS | 0 | 0 | |
| | GS | 36 | 0 | |
| pescara | WS | 278 | 0 | |
| | GS | 58,500 | 0 | |
| Total Cummulative Papers | | | | 49 |
| GSB-centric Paper | | | | 18 |
| GSB-centric Paper - Data California (only) | | | | 15 |
| GSB-centric Paper - Data Mexico (only) | | | | 0 |
| GSB-centric Paper - Data U.S. and Mexico | | | | 3 |

Table 2.1.2. Economic investment on GSB research and conservation.

| Country | Institution/Person | GSB Project Topics | Period | Years | Funds allocated (US$) |
|---|---|---|---|---|---|
| U.S. | Aquarium of the Pacific | GSB Conservation | 2016-2019 | 3 | $35,000 |
| | Cabrillo Aquarium | YOY GSB grow & release | 2018-2019 | 1 | $37,000 |
| | CSU Long Beach | Aggregation site fidelity | 2015-2020 | 4 | $50,000 |
| | CSU Northridge | Age-Growth, Population genetics, Distribution, Courtship behavior, YOY distribution, Sound production | 2010-2020 | 9 | $30,500 |
| | M. Couffer/ Grey Owl Biological Consulting | Nursery habitat and Distribution of YOY | 2015-2020 | 4 | $27,697 |
| | M. Domeier - CDFW | Adults movements patters, Habitat preferences, Reproductive biology, Population genetics, Fishery | 2000-2009 | 8 | $400,000 |
| | Pfleger I.E.S. | Adults movements patters, Habitat preferences, Fishery | 2002-2006 | 4 | $70,000 |
| | SIO | Adults movements. Trophic ecology. GSB conservation | 2012-2020 | 7 | $42,000 |
| | UCSB | Population size. Economic Value. Spotting GSB website | 2014-2020 | 5 | $42,000 |
| US Total | | | 2000-2020 | 19 | $734,197 |
| Mex | SIO/ Proyecto Mero Gigante | Age-Growth, Population size, Aggregation site, Fishery, Populations genetics | 2017-2020 | 3 | $25,000 |
| | COBI | Population size, Aggregation site, Fishery, Populations genetics | 2018-2020 | 1 | $5,000 |
| | UABC/ Proyecto Mero Gigante | Populations genetics | 2018-2019 | 1 | $500 |
| Mex Total | | | 2017-2020 | 3 | $30,500 |

Table 2.1.3. GSB Weight and Length resulting from the biological monitoring program.

| Location | N | Weight (kg) Average (min-max) | Total length (cm) Average (min-max) |
|---|---|---|---|
| Fish Market Ensenada | 61 | 32.01 | 95.22 |
| Fish Market Tijuana | 51 | 10.62 | 71.39 |
| Guerrero Negro (BCS, Mx) | 56 | 33.8 (1—170) | 100.6 (42—197) |
| Laguna San Ignacio (BCS, Mx) | 37 | 9.9 (1—117) | 76.1 (3—195) |
| Las Barrancas (BCS, Mx) | 23 | 36.1 (12—90) | 119.0 (84—177) |
| El Rosario (BC, Mx) | 16 | 44.4 (3—280) | 83.8 (60—131) |
| Bahía Tortugas (BCS, Mx) | 15 | 4.0 (0.4—18) | 53.5 (31—83) |
| Laguna Manuela (BCS, Mx) | 11 | 97.0 (6—192) | 137.9 (65—220) |
| Bahia Magdalena (BCS, Mx) | 8 | 95.0 (37—210) | 169.3 (138—251) |
| Bahia de los Angeles (BC, Mx) | 6 | 56.7 (9.2—140) | 93.5 (77—110) |
| Erendira (BC, Mx) | 5 | 2.9 (1.7—6.9) | 54.2 (45—76) |
| San Juanico (BCS, Mx) | 4 | 44.2 (4.6—160) | 73.6 (71—76) |
| La Jolla (CA, US) | 3 | - | 114 (77—148) |
| Popotla (BC, Mx) | 3 | 46.0 (33—60) | - |
| Punta Abreojos (BCS, Mx) | 3 | 40.3 (4.9—68) | 105.0 (69—141) |
| San Felipe (BC, Mx) | 3 | 45.0 (33.6—67) | 122.0 |
| Isla Natividad (BCS, Mx) | 2 | 29.5 | 120.0 |
| Islas Coronado (BC, Mx) | 2 | 50.0 (45—55) | - |
| San Luis Gonzaga (BC, Mx) | 2 | 17.0 (14.2—19.9) | - |
| Other | 10 | 74.4 (10—180) | 133.6 (35—230) |

# FIGURES

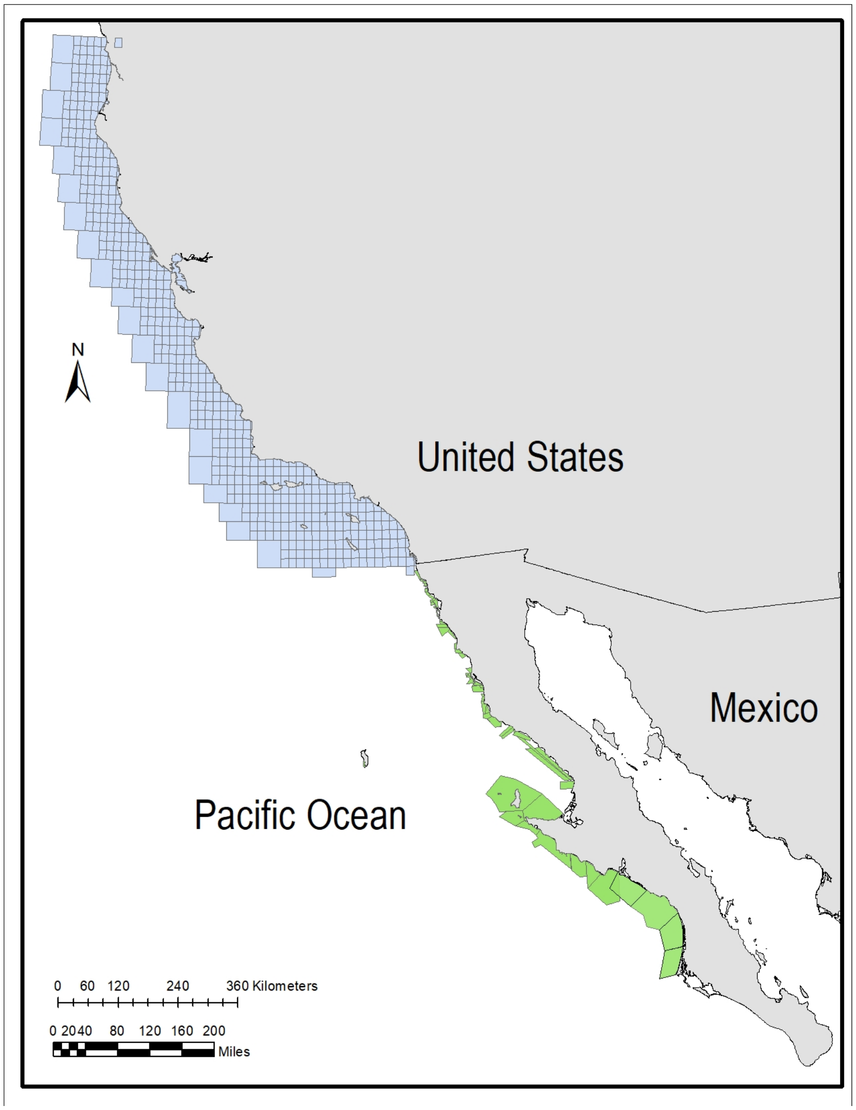

Figure 2.1.1. Study area and the spatial management of the fishery in both geographic regions; 10 × 10-minute grid blocks by California Department Fish and Wildlife (U.S.) and fishery concession areas by Mexican Fisheries Management Agency-CONAPESCA (Mexico).

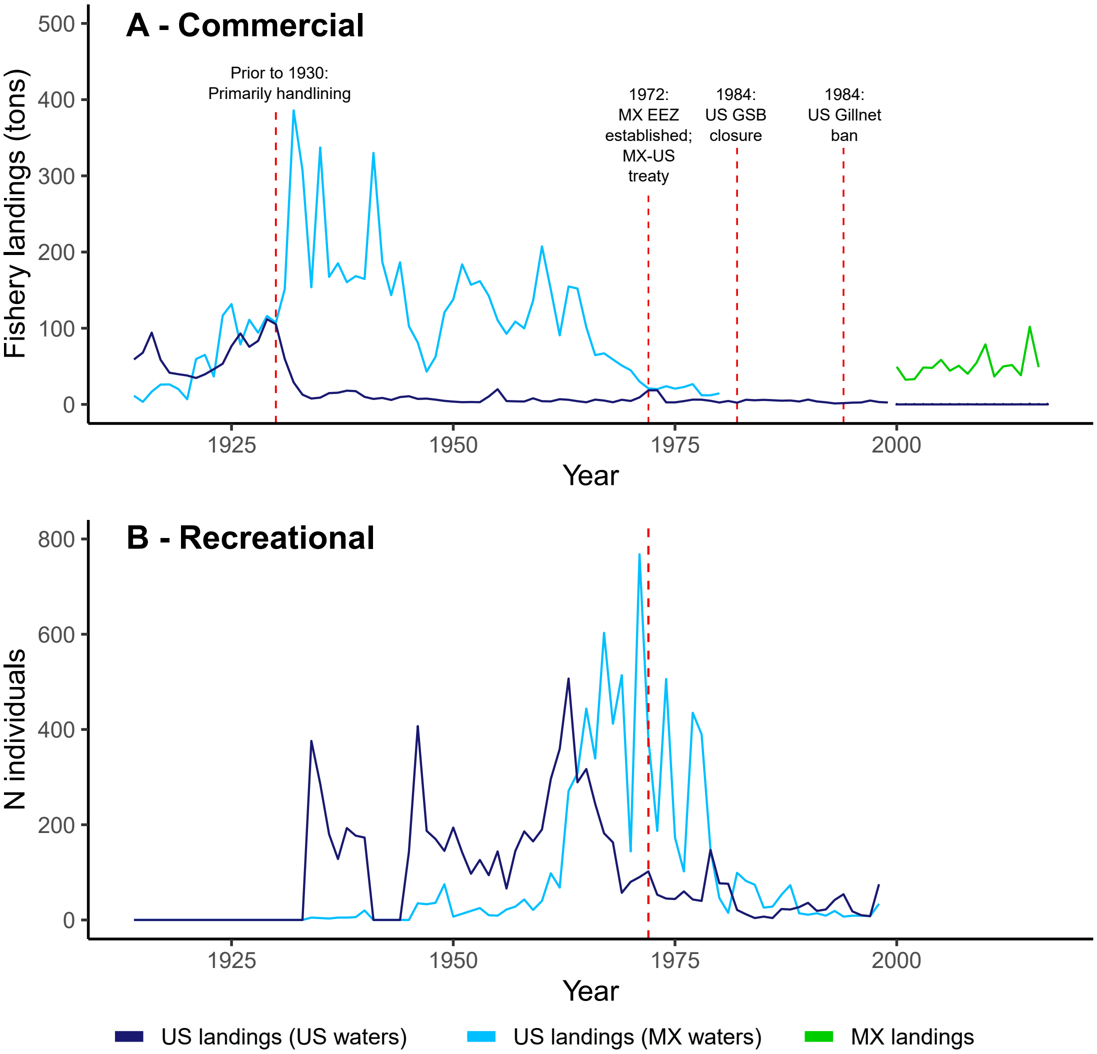

Figure 2.1.2. Historic and contemporary fishery landings of Giant Sea Bass in the U.S. and Mexico show strong variability over time. Historical data on commercial catches shows that population collapse in the U.S. waters occurred in the 1930s, much earlier than previously thought (A). Recreational catches in Mexican waters showed a peak after the apparent collapse of the commercial fishery occurred (B). Additionally, contemporary catches in Mexico have remained remarkably consistent, averaging 50.9 ton/yr.

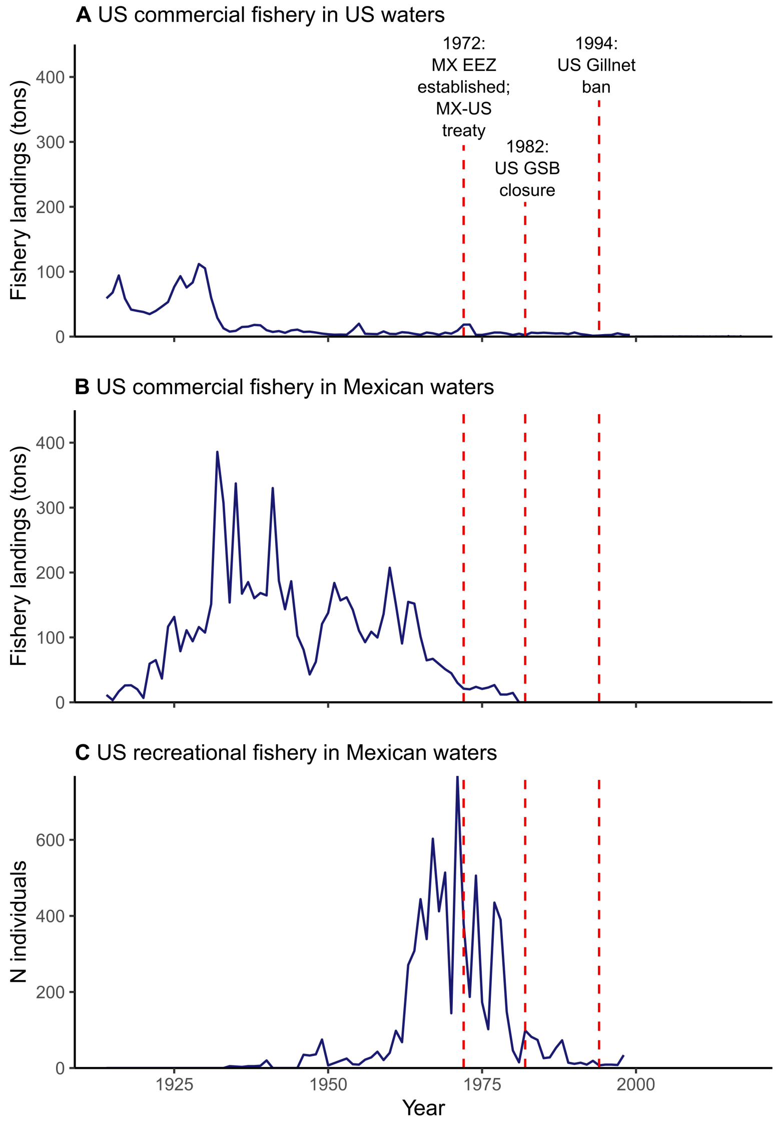

Figure 2.1.3. Commercial and recreational fishery landings of Giant Sea Bass from the U.S. fleet. A) U.S. commercial fishery in U.S. waters, B) U.S. commercial fishery in Mexican waters, and C) U.S. recreational fishery in Mexican waters. EEZ= Enforcement of Economic Exclusive Zones started in 1972 in both, the U.S. and Mexico. Data source: U.S.: CDFW (2001) and CDFW dataset (2000-2017). Despite the perceived collapse of Mexican GSB populations in 1972, the U.S. recreational catches from Mexican waters indicate that political legislation (rather than population collapse) was truly limiting catches before 1980. Data source: U.S.: CDFW (2001) and CDFW dataset (2000-2017). Mexico: CONAPESCA dataset (2000-2017).

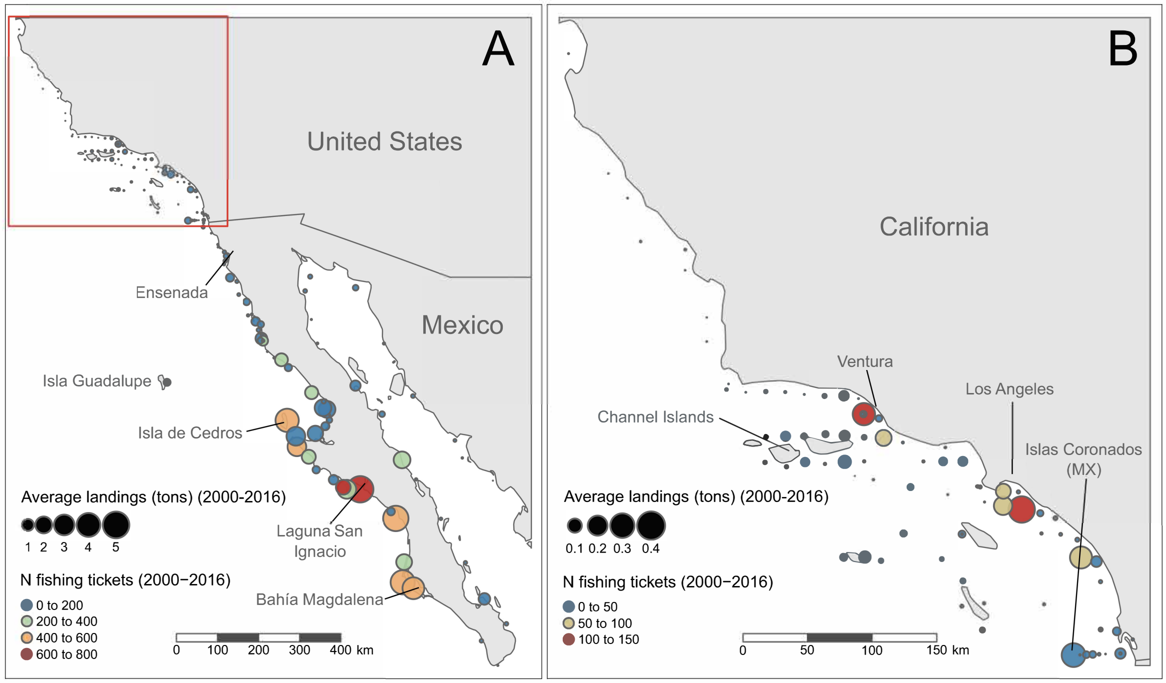

Figure 2.1.4. Spatial representation of the contemporary 2000-2016 annual average fishery landings of giant sea bass from the U.S. and Mexico commercial fleets shows much higher landings in Mexico. A) Fishery landings in the entire GSB distribution range; B) Fishery landings in the U.S. region. Number of events (tickets) represents the times that GSB has been caught in a specific fishing ground. Data source: Mexico = CONAPESCA-SEPESCA official landings; U.S.= CDFW fishery Landings.

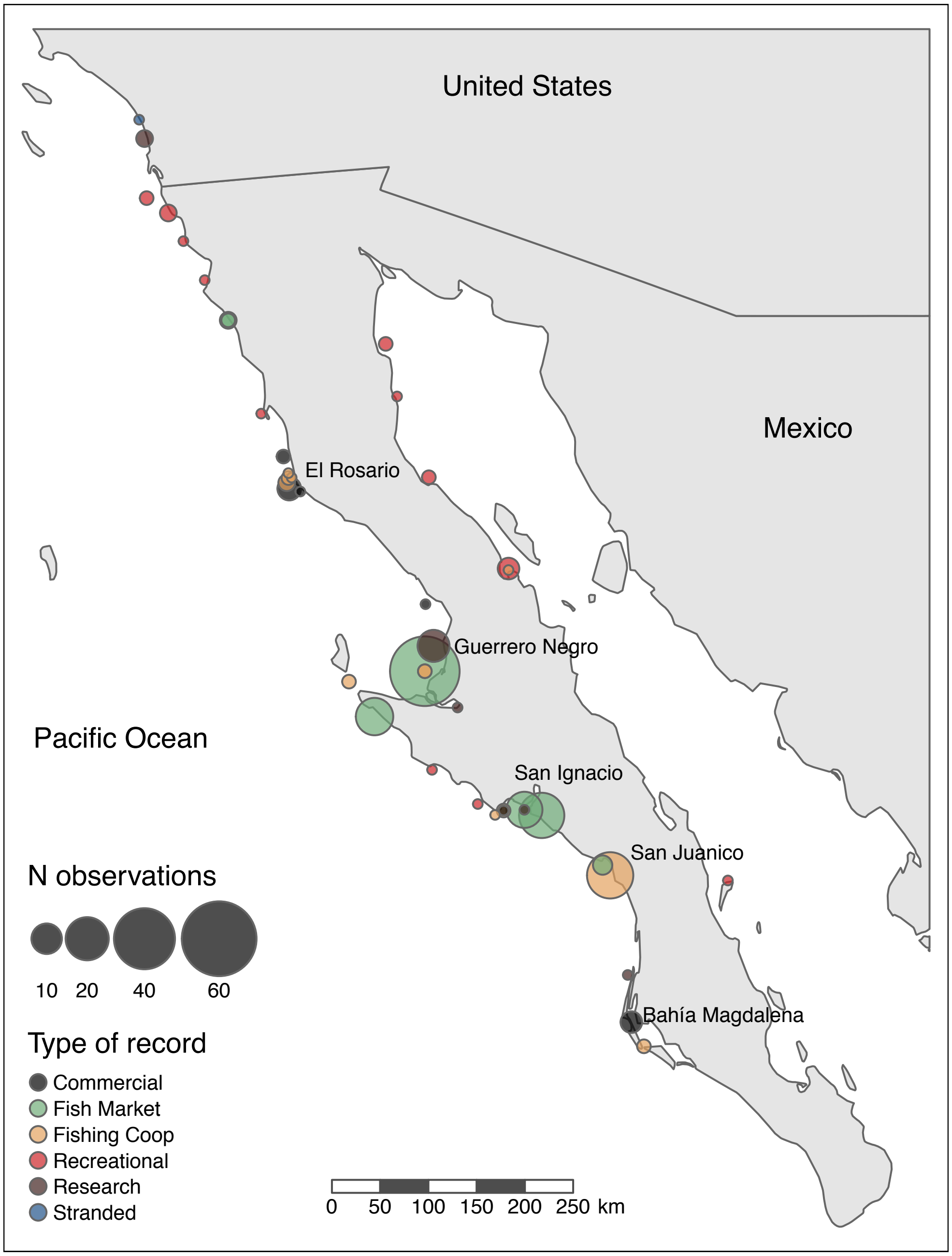

Figure 2.1.5. The GSB fishery monitoring program sample a wide geographic range of sites along the Baja California Peninsula (Mexico) and California (U.S.) using a diverse set of sources. N observation = number of samples from each location.

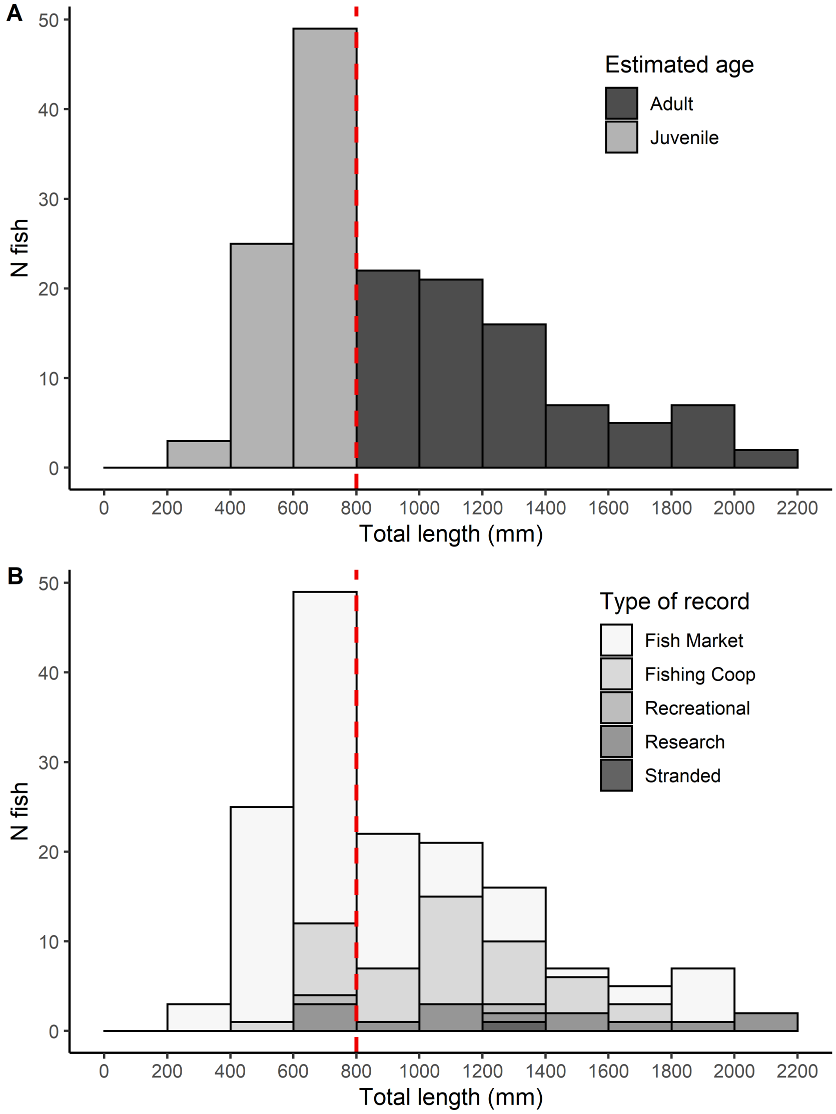

Figure 2.1.6. Total length of 157 samples of giant sea bass sampled through the fishery monitoring program. 48.4% of samples were shorter than 800 mm TL, indicating that many individuals may be juveniles (after Hawk & Allen, 2014).

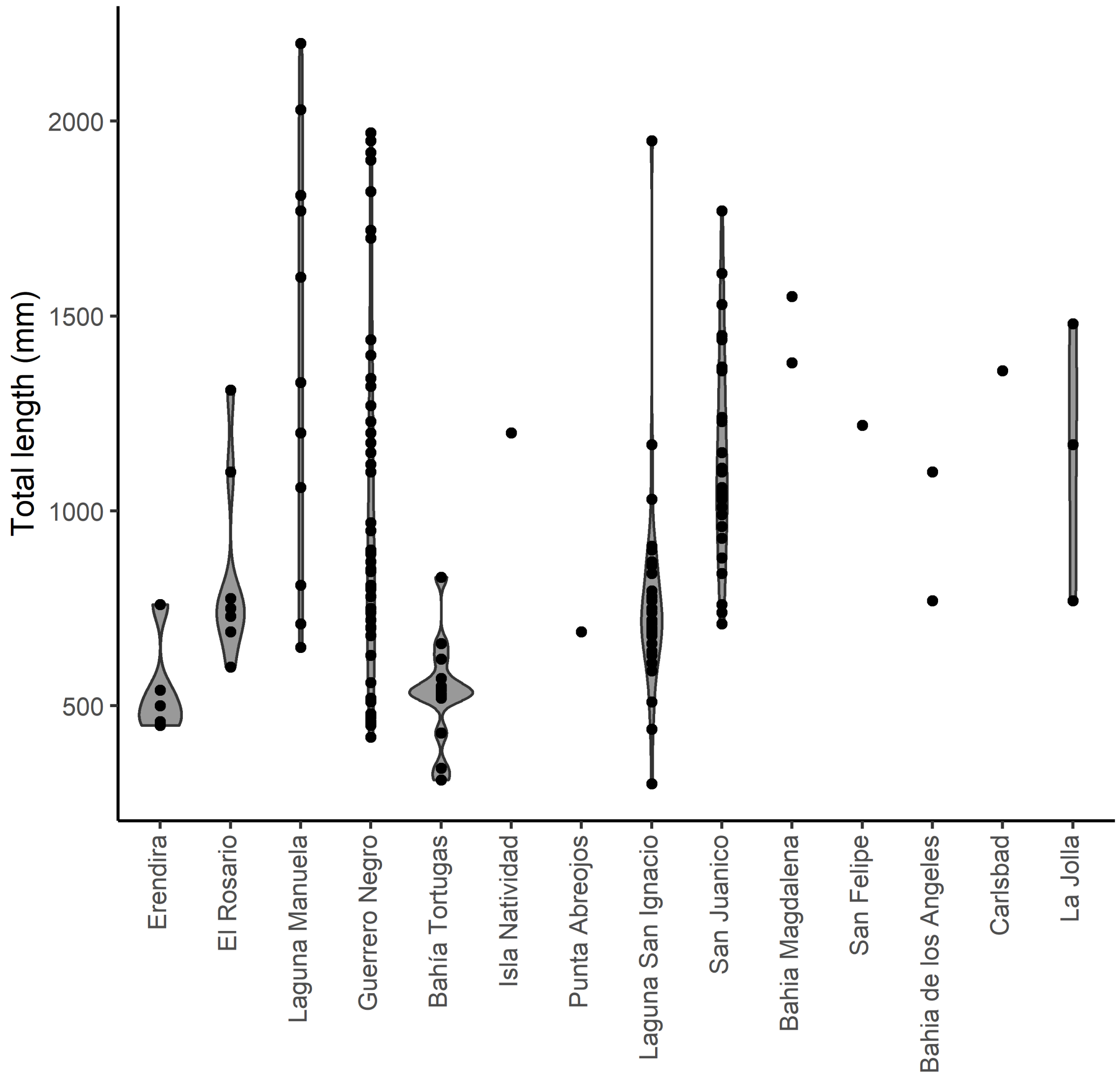

Figure 2.1.7. GSB weight distribution by catch site resulted from the Mexican fishery monitoring program.

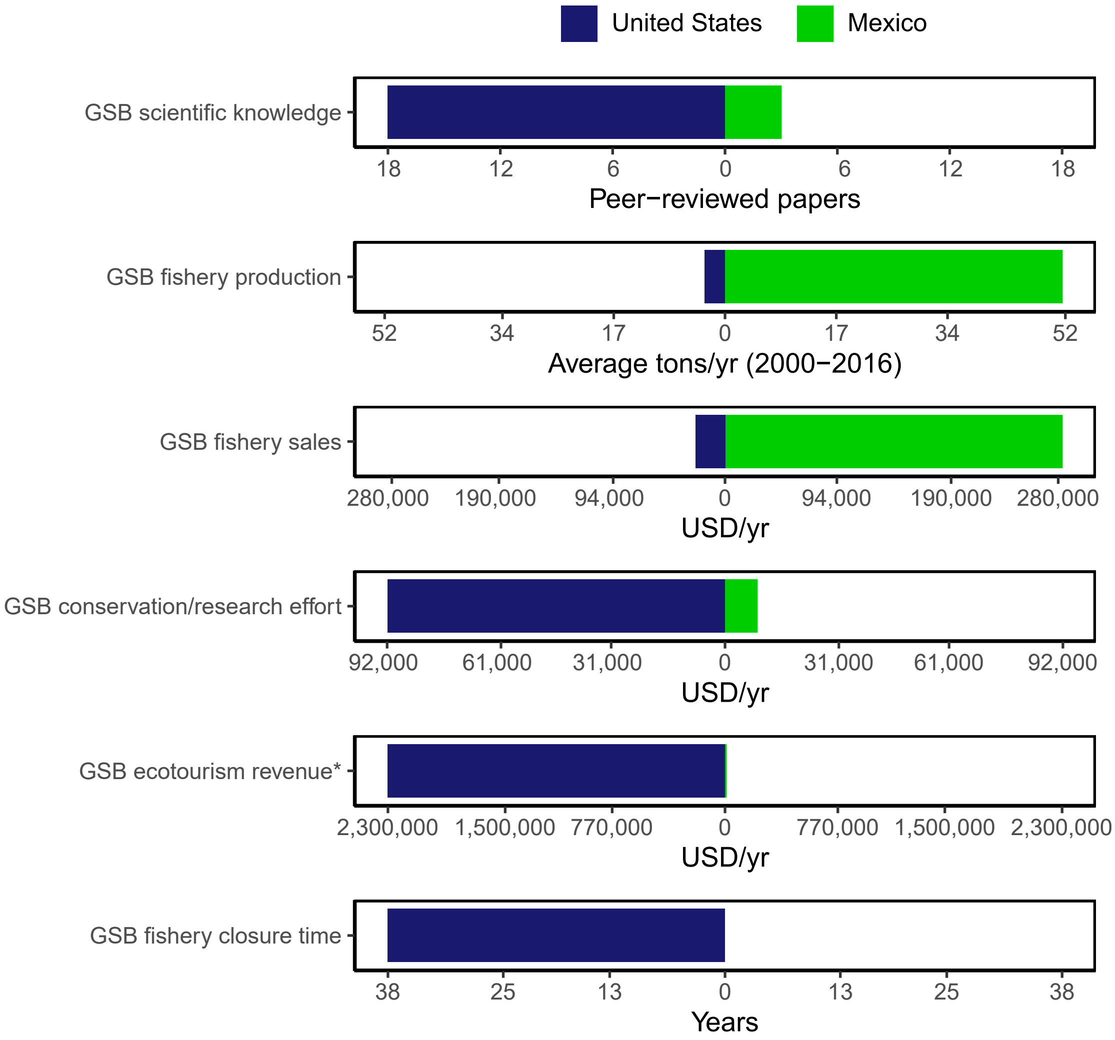

Figure 2.1.8. Management of the GSB across the U.S.-Mexico border is highly asymmetric. Despite little economic or scientific input in Mexico, fishery catches, and revenue remains high. This trend is reversed in the United States. GSB ecotourism revenues after (Guerra et al., 2017).

# CHAPTER 2

## Asymmetry in the management of marine resources across political borders

“Case Study 2”

## The economic value of the kelp forest ecosystem services across political boundaries: an approach with commercial fishery ex-vessel value

Arturo Ramírez-Valdez

# ABSTRACT

Kelp forests are ecosystems prevalent in temperate shallow rocky reefs that provide ecosystem services to humans. On the Pacific coast of North America, iconic giant kelp forests are a shared ecosystem distributed across Mexico and the United States (U.S.) border and which connects species' populations and sustains diverse marine communities. However, current trends show that coastal towns and cities will continue to grow in the region, increasing the anthropogenic pressures on kelp forests. Furthermore, there is no robust estimation of the economic impact nor the habitat loss and subsequent loss of biological diversity caused by the increasing anthropogenic impacts. By using remote sensor technology with Landsat satellite images, we obtained the kelp forest cover and analyzed its temporal trends within Fishing Management Areas (FMA) that we associated with information on the fishery landings of species that rely on this ecosystem. Giant kelp cover showed a decrease in El Niño events and an increase during La Niña. The cover decrease related to warm waters is more prolonged and severe at the southern limit of its distribution. We found a positive correlation between kelp cover and fisheries landing for species such as lobster, sea urchin, and abalone. We also found a non-significant positive relationship for giant sea bass and California sheephead fisheries. The economic value of the kelp forest ecosystem by area coverage was up to 20 times higher in Mexico (US$6 million $Km^2$/yr) than in California (US$250,000 yr), based on the total fisheries value. The abalone fishery has the highest economic value (US$5.3 million yr), while the red sea urchin fishery has a better economic value per kelp coverage ratio (US$290,000 $Km^2$/yr).

This represents the first effort to assess the economic value of the kelp forest ecosystem throughout its distribution in the Northeastern Pacific and proposes a binational perspective on the understanding and management of the marine resources.

## INTRODUCTION

Marine ecosystem services are seriously undervalued, resulting in a general under-investment in conservation and many lost opportunities for economic growth and poverty reduction (Costanza et al., 1997; Lange and Jiddawi, 2009). Economic valuation provides a powerful tool for sustainable development by showing how dependent economy really is on an ecosystem, and by illustrating what could be the social impact if the ecosystem service it is not protected (Beaumont et al., 2008). Paradoxically, direct users and policy-makers, who appreciate consumptive uses the most, have historically undervalued these ecosystems. Although consumptive uses represent only a small proportion of an ecosystems' total value, economic data generated by these uses are the most frequent type of data available to valuate ecosystem services.

Kelp forests are an ecosystem that provides a wide range of services for human populations including: food and natural products, recreational and commercial fisheries, ecotourism opportunities, cultural value, nutrient cycling, and the resilience of marine and coastal ecosystems (Pendleton and Rooke, 2010; Tegner and Dayton, 2000a; Wilmers et al., 2012). Although poorly valuated to date, these services nevertheless are vital to human welfare. Among these ecosystem services, those of direct use such as commercial fisheries, represent an important economic and social component. General estimations highlight that compared with other ecosystems, kelp forest ecosystem services rank among the highest in economic value (Costanza et al., 1997). Among these ecosystem services, those of direct use such as commercial fisheries, represent an important economic and social component.

On the Northeastern Pacific coast, the forests formed by giant kelp (*Macrocystis pyrifera*) are the most biodiverse and productive marine ecosystems that provide food, create habitat, and sustain trophic webs (Dayton, 1985; Schiel and Foster, 2015). Species part of these kelp forests' trophic webs are among those that represent an important fishing value and support the economy of many coastal towns and cities across two nations, the United States (U.S.) and Mexico. The kelp forest ecosystems in this region have experienced two very different histories in their fisheries management; along the coast of California (U.S.), a long history of fishing pressure and later collapse of economically important fisheries (Tegner and Dayton 2000), early efforts of spatial fishery management, and more recently the implementation of marine reserves networks (Marine Life Protection Act). Contrastingly, the kelp forests off the coast of the Baja California Peninsula (Mexico), have experience more recent fishing pressure and efforts to improve fishery management, yet are still without marine protected areas. In general, fishing is an important economic activity through the distribution of the kelp forest across the U.S.-Mexico border. For instance, California commercial and recreational fishery generated approximately US$24.9 billion in sales and more than 142,000 direct and indirect jobs in 2016 (NOAA, 2016). While ex-vessel revenues for the commercial fishery in the Baja California Peninsula region (Baja California and Baja California Sur), generated approximately US$228 million and more than 8,000 direct jobs in 2016 (CONAPESCA 2018, SEPESCA 2016). These economic benefits support an important social structure in the region beyond sales and direct jobs; this economy impacts tourism, food industry, and has roots in the local communities of both countries.

There are several important commercial and recreational fisheries of species of invertebrates throughout this region that support social well-being and are part of the ecosystem services that giant kelp forest provide, such as abalone (*Haliotis* spp.), spiny lobster (*Panulirus interruptus*) and sea urchins (*Strongylocentrotus purpuratus* and *Mesocentrotus franciscanus*), as well as fish such as giant sea bass (*Stereolepis gigas*) and California sheephead (*Semicossiphus pulcher*). (Love et al., 1998; Schroeder and Love, 2002). The spiny lobster, red sea urchin, and purple sea urchin represent a good example of the asymmetry in management and economics associated with their fishery across the U.S.-Mexico border (Fig. 1). These shared stocks are being fished with comparable techniques; however, the associated catch and the economy are significantly different.

Despite the ecological and economic importance of the giant kelp forest ecosystem, there has only been a limited focus of conservation efforts across its distribution in both the U.S. and Mexico. Although there is information on some of the ecosystem services that kelp forests provide to humans in the region, as far as we know, there is not published information that integrates these ecosystem services and relates them to kelp forest cover. An effort to study this ecosystem from a binational perspective is also absent, which would make ecological and economic sense, as it encompasses its entire distribution and both countries share the majority of economically important species. In ecosystems shared between nations, such as kelp forest, the actions taken by one nation invariably affect the other.

Ecosystem services valuation represents a powerful tool for decision-making based on the economic value of marine resources, allowing to identify opportunities to improve marine management and sustainable development. Here we estimate the economic value of the giant kelp forest ecosystems across the entire geographic distribution in the Northeastern Pacific, based on some of the most important fisheries in the region. To test the hypothesis that the kelp cover has a direct bearing on the production of commercially important fisheries, we evaluated the giant kelp cover inside Fishery Management Areas (FMA) that span all the geographic distribution of the giant kelp and compared it with the fisheries production within those FMA. Overall, an economic valuation will contribute to better-informed decision-making to protect these ecosystems.

## MATERIAL AND METHODS

### Study area

Giant kelp (Macrocystis pyrifera) distribution range in the Northeastern Pacific extends from Sitka, Alaska (U.S.) to south of Punta Eugenia, Baja California Sur (Mexico), however, well-defined submerge forests can only be found south of Santa Cruz, California (Cavanaugh et al., 2019; Macaya and Zuccarello, 2010; Schiel and Foster, 2015). This study spans the whole distribution of submerged giant kelp forests, which encompass more than 10 degrees of latitude (approximately 1,600 km), from Seal Rock, Santa Cruz (U.S.) (36.5º N) to the southern range limit near Bahía Asunción, Baja California Sur (Mexico) (27.1º N). Giant kelp in the west coast of North America occurs primarily on shallow rocky reefs (5-25 meters) that are distributed in patches.

The main oceanographic driver in this region is the California Current System

(CCS), which is one of the five most productive marine ecosystems on the planet (Checkley and Barth, 2009; McClatchie, 2014). The high productivity of the CCS is mainly attributed to Equator-ward transport of temperate waters, as well as favorable winds for coastal upwelling, which together generate an offshore transport of surface waters and advection of relatively cold and nutrient-rich waters to the surface (Checkley and Barth, 2009).

### a) Spatial approach

We used 182 Fishery Management Areas (FMA) along the study area (Fig. 1; Table 2). The FMA are polygons representing ocean habitat used by the U.S. and Mexico fishery government agencies to spatially manage marine fisheries. The Mexico's FMA are 81 "commercial fishing concessions polygons" granted to fishermen cooperatives by CONAPESCA (The National Commission for Fisheries and Aquaculture). The Mexican FMA essentially function as Territorial Use Rights for Fisheries (TURFs) for fishers from coastal communities. In the case of the U.S., the FMAs are 10 × 10-minute grid blocks established back in the 1930s by the California Department Fish and Wildlife (CDFW). These 10 × 10-minute grid blocks extend throughout California coast within the Economic Exclusive Zone of the U.S. and are used for spatial management of all fisheries. We integrated all FMA in a Geographic Information System (GIS) using ArcGIS v10.8 to facilitate spatial analysis. In the case of Mexico, 74 fishing concessions granted to species that rely on the giant kelp forests were used. For the U.S., we filtered 101 out of 554 10 × 10-minute grid blocks that were within a 30-meter-deep bathymetry layer along the coast from the U.S.-Mexico border to Santa Cruz, California and the Channel Islands.

### b) Kelp cover

Giant kelp (Macrocystis pyrifera) forest cover (km2) within all 182 FMA was estimated using high-resolution satellite imagery. We used images of the Landsat 5 Thematic Mapper sensor with 30 m spatial resolution nearly continuously from 2000 to 2017. The satellite image processing followed the same methodology used for the terrestrial vegetation as the spectral signature of a giant-kelp canopy is similar to that of photosynthetically active terrestrial vegetation (Fig. 3) (Cavanaugh et al., 2010; Jensen et al., 1980). Landsat 5 Thematic Mapper obtains data in 7 spectral bands: blue (450 to 520 nm), green (520 to 600 nm), red (630 to 690 nm), near-infrared (760 to 900 nm), short-wave infrared (1500 to 1750 and 2080 to 2350 nm), and longwave (thermal) infrared (10400 to 12500 nm) (Cavanaugh et al., 2011). The kelp near-infrared (Band 4) radiance signal, while elevated compared to that of water, spans only the lowest ~40 brightness values detectable by Landsat 5 Thematic Mapper. Each of the Landsat scenes covers an area 170 × 180 km, so multiple scenes were used to cover the entire study region (Fig. 1). During preprocessing, Landsat images were geometrically corrected using ground control points and a digital elevation model to achieve a scene-to-scene registration accuracy <7.3 m (Lee et al. 2004). We were able to discriminate zero values due to the absence of kelp from zero due to satellite image reading errors (i.e. clouds, wind). We developed an automated classification and quantification process in order to consistently and efficiently transform the Landsat 5 Thematic Mapper images into maps of kelp canopy cover. A detailed method of procedure and image calibration is described in Cavanaugh, Siegel, Reed, & Dennison, (2011) and Bell, Cavanaugh, Reed, & Siegel (2015).

We obtained annual average kelp cover values for each FMA from seasonal values.

FMA with values of zero in the entire data series were eliminated, assuming the non-existence of the specific giant kelp habitat.

### c) Fishery landings and revenues

Commercial fishery landings datasets from 2008 to 2017 were obtained from fishery government agencies for three commercially important invertebrate species that rely on the kelp forest ecosystem; spiny lobster (*Panulirus interruptus*), red sea urchin (*Mesocentrotus franciscanus*), and purple sea urchin (*Strongylocentrotus purpuratus*). In addition, two fish species, California sheephead (*Semicossyphus pulcher*), and giant sea bass (*Stereolepis gigas*), and the abalone's species-complex were included in the analysis, all of whom are important in the maintenance of the kelp forest ecosystem trophic web and with asymmetric fisheries management across the U.S.-Mexico border. Mexican commercial fishery landings were obtained from the Mexican federal fishery agency CONAPESCA. The U.S. commercial fishery landings were obtained from the California Department of Fish and Wildlife (CDFW). In both cases, the U.S. and Mexico fishery landings were obtained from fishing tickets, which include species, catch site FMA-associated, and date.

Fishery landings were analyzed independently by species, and annual Fishery Production was obtained by dividing annual fishery landings (kilograms) by the area within the FMA (square-km):

$$Fishery\ Production = \frac{Fishery\ landings\ (Kg)}{FMA\ (Km^2)}$$

We obtained the economic revenues for each fishery using the official price for each species reported by government agencies. For the U.S., the revenues for each fishery were calculated with the average annual market price per pound (converted to kg) reported by the CDFW and were corrected for inflation to 2018 by using the Consumer Price Index (World Bank). In the case of Mexico, we used the same market prices reported by the CDFW.

### d) Kelp cover size versus fishery production

We selected 10 years (2008-2017) where the kelp cover and commercial fishery landings overlap was greatest. We performed the analysis using the percentage of kelp cover within the FMA, due to the variability of the FMAs area and therefore the area of kelp coverage inside. The giant kelp coverage within each FMA was transformed into a percentage of coverage from the total area:

$$\%FMA\ Kelp\ cover = \frac{Kelp\ coverage\ (Km^2)}{FMA\ (Km^2)}$$

The %FMA kelp cover was classified in three categories based on the data distribution: Low coverage (<0.1% of kelp cover within the FMA), Medium (between 0.1 – 1.0% of FMA kelp cover) and High (> 1.0% of FMA kelp cover). The number of FMA in each of the kelp cover categories was variable by year and by species. In the case of the U.S., the FMA is the same for all the species analyzed. In the case of Mexico, for most cases, the FMA is the same, but there are a few exclusive FMAs for lobster and sea urchin fishery. The summary of FMA in each kelp cover category is presented in Table 1.

### e) Statistical analysis

We tested differences in FMA size between countries and within countries (t-test). In addition, we tested differences in FMA kelp coverage by latitude, using the geographic location of each FMA with respect to the polygon centroid. We also tested differences in FMA kelp coverage between countries and within countries. We use linear regressions to test the relationship between kelp coverage and fish production for each fishery. The significance of the fishery production between the kelp cover size within the FMA was tested using 1-way analysis of similarities (ANOSIM). While the significance of the fishery production between the kelp cover size within the FMA and between countries was tested using 2-way ANOVA.

## RESULTS

### a) Spatial approach

The area and shape of the 182 FMA varied between and within the U.S. and Mexico. The average area of the FMA was 252 km2 (± 582.05 SD), with a minimum value of 0.9 km2 and a maximum value of 5,379 km2 (Table 2). The size of the FMA within countries was even more variable, the mean size for the U.S. FMA was 191 km2 (± 94.05 SD), while the mean size of the FMA in Mexico was 327 km2 (± 860.72 SD). There are major differences between the FMA of both countries, the shape, the location with respect to the coast, and the management of the fisheries within them are just some of these differences. The t-test ($t = 0.679$; $P < 0.01$) shows significant differences in area between FMAs in the U.S. and Mexico.

With the exception of the fishing concessions on the islands, the Mexican FMAs are distributed along the coast according to the availability of the habitat, and their amplitude extends according to the depth at which the species included in the fishing concession are distributed. On the other hand, the U.S. FMAs extends to greater depths of the kelp distribution.

### b) Kelp cover within FMA

On average, the U.S. FMAs have higher kelp cover compared to those located south of the U.S.-Mexico border. The two-way ANOVA analysis showed significant differences between the kelp coverage within the FMA with respect to latitude and year. The year 2013 had the highest kelp coverage, while 2016 was the year with the lowest kelp coverage. The kelp coverage within the FMAs was variable over time and also across the geographical range of distribution. Neither the latitudinal gradient ($R^2 = 0.009$; $P = -0.03$) nor another geographic pattern was detected. The size distribution of kelp cover within the FMAs showed most of them had less than 1% kelp coverage within them, with a mean of 0.45%.

### c) Fishery landings and revenues

We found a slight increase in the fishery production across the entire geographical range studied in the last 17 years (2000-2017), with a mean of 118 kg/km2. The fishery production (landings/area) in all resources evaluated is greater in Mexico than in the U.S. Although differently than in Mexico, the U.S. production of the 3 benthic species has remained very stable throughout the last 17 years. Revenues as a result of the fishery production follow the same pattern, being higher in Mexico for all fishery resources evaluated.

### d) Kelp cover size versus fishery production

The fishery production increases when the kelp cover area within the FMAs is higher in the case of spiny lobster, purple sea urchin, red sea urchin, and abalone (one-way ANOVA, $P = < 0.05$; Fig. 4 and 5). Although the relationship between fishery production and kelp cover was not significant for all fisheries evaluated (Table 3), the difference between the kelp cover categories; high, medium and low, was significant. The greater the kelp cover inside the FMAs, the greater the production of the analyzed fisheries. This difference was not significant in the two fish species, where even when the same pattern of greater fishing production with greater kelp cover, however, the differences between the categories were not significant.

## DISCUSSION

Our results show that the value of the ecosystem services provided by the kelp forests may be higher than US$9 million per year, considering only the extractive services of the commercial fishery, which represent a small fraction of all the benefits we obtain from this ecosystem. This study provides relevant information for managers and decision-makers with implications for public policies in the regulation and conservation of the coastal resources of both countries, the U.S. and Mexico. Giant kelp forests are not only the most productive marine ecosystem in the region, but also support economically important species (Tegner and Dayton 2000). Considering only the abalone fishery in

Mexico, for example, the economic value of production can be up to US$8 million in a fishing season. Unlike other services that ecosystems provide to humans, in this case, the loss of the giant kelp forest would also represent the total loss of some of these fisheries as they are highly dependent on the existence of giant kelp for their subsistence.

The contrast of the fishery production of the same species (i.e., lobster, red sea urchin, and purple sea urchin) in the U.S. and Mexico is an excellent example of how management beyond biological factors or the market is decisive in the benefits we get from the fisheries. When comparing the geographical distribution of these three species and their ecological densities, the differences across the U.S.-Mexico border are not significant (Edwards and Estes 2006, Torres-Moye et al. 2014). The pressure that economic markets exert on these resources applies equally to the products from both sides of the border since both Mexico and the U.S. export their products to Asia (CDFW 2016, SEPESCA 2018). Even when both countries have management by quotas and size limits, probably the most significant difference is that Mexico's fisheries management is by territorial-use rights (TURF). In contrast, in the U.S., fisheries are managed through individual licenses.

The asymmetry in the fisheries management across the U.S.-Mexico border explains, for the most part, the differences in production. Management differences include the designation of fishing grounds, recreational fishing permits for important commercial species, and individual fishing permits versus territorial concessions. Fishing concessions in Mexico are assigned to organized groups of fishermen called cooperatives, who fish or harvest one or more resources inside the same FMA. In the U.S., permits are granted to individual fishers, and these permits are not linked to a specific fishing ground or FMA. Although it may seem that in both cases the fishing effort is stable over time, in the case of

Mexico, no more fishing concessions have been granted and the fisher members are constant, while in California the number of active fishers has been relatively stable since 2003 (CDFW 2016), the major difference can occur in terms of the pressure to specific fishing grounds, the number of traps used, and the possibility of transferring individual permits.

The greater fishing production in Mexico of benthic species (i.e., spiny lobster, sea urchin) is the result of the combination of greater fishing landings and FMAs specifically directed to the habitat of these resources. While lobster fishing landings are higher in Mexico, this is not the case for the two species of sea urchin. Unlike the FMAs in California, the FMAs in Mexico are mostly smaller areas and specially designated to areas where the species is present at a density enough to support a fishery. The design of the FMAs in the U.S. represents a standardized management for all the fishing resources, independently of their ecological density inside the polygon, even if the species density is low enough to not support a fishery. The FMAs in Mexico were designed to set polygons in areas where the presence of the species can support a fishery.

Our analysis successfully shows a positive relationship between the giant kelp forests cover and the fishery production of the analyzed fisheries. The higher the percentage of giant kelp cover within the FMAs, the greater the production of the fisheries. This relationship is even more significant in those species that depend directly on giant kelp, such as abalone and sea urchin species (Leighton 2000, Tegner and Dayton 1981). Even though lobster does not feed on giant kelp, their most common preys do, which is why other studies have found the same relationship between giant kelp density and spiny lobster (Guenther et al. 2012).

The relationship between the percentage of giant kelp cover within the FMAs and the fishery production was positive but not significant for the two fish species. Both species of fish are common residents of the kelp forests, and studies have analyzed their close relationship with this ecosystem (Tegner and Dayton, 2000b). While California sheephead is probably the most important predator of adult sea urchins and they can become the largest component of their diet, giant sea bass feed on a wide variety of invertebrates associated with giant kelp (Domeier, 2001; Hamilton and Caselle, 2015). However, these species are also commonly found on rocky reefs on the edge of kelp forests, areas that are frequently visited by fishers.

Contrary to what previous studies reported, our results do not show an effect of a trophic cascade in the kelp forests as a result of fishing for predators of this system (Guenther et al., 2012; Lafferty, 2004; Tegner and Dayton, 1981). Fishing can trigger a trophic cascade effect on ecosystems by selectively changing the abundance of specific species and thus altering the composition and structure of communities (Tegner and Dayton, 1981). In this case, the extraction of lobsters by the fishery could increase the abundance of sea urchins which, due to the grazing effect, would decrease the giant kelp cover. Guenther et al. (2012) found no evidence that the lobster fishery indirectly impacted giant kelp biomass through increased urchin abundance, however, they reported a decrease in urchin abundance due to the top-down effect. In contrast, our results indicate that both, lobster and sea urchin show greater abundance in the presence of greater giant kelp cover.

Our results show that the positive relationship of giant kelp cover and sea urchin-lobster fishery production is maintained throughout the entire geographic distribution of giant kelp forests and across a political border, which implies wide differences in the fisheries management scheme. The giant kelp forests in the Northeastern Pacific are fairly equally present in coastal extent in both the U.S. and Mexico, and our results coincide with previous studies in pointing out that the density of giant kelp does not show a latitudinal gradient across this geographic region (Edwards, 2004; Edwards and Estes, 2006). On the other hand, both countries exert fishing pressure on both the spiny lobster and sea urchin and, in most cases, within the same FMAs. Asymmetries in the spatial management of fisheries, including the number of species being fished, fishing quotas, and fishing pressure per habitat, can be a limiting factor for this relationship to be maintained. Although previous studies have shown the positive relationship between giant kelp cover and spiny lobster production, and giant kelp cover and sea urchin production, what makes an even more persuasive argument is this study successfully shows this relationship across different geographic areas and different management schemes (Guenther et al., 2012; Tegner and Dayton, 1981).

This study successfully shows that the economic value of kelp forests ecosystem is significantly higher than previously thought, considering only the value of the commercial fishery. Previous work has directed efforts to economically value algal beds and kelp forests, considering different ecosystem services (Costanza et al. 1997, Vasquez et al. 2014). Costanza et al. (1997) assigned a value of US$19,004 ha/yr to algal beds from a global perspective, while Vasquez et al. (2014) valued the kelp forests in northern Chile in US$540 million per year. Our results indicate that the value of giant kelp forests can reach a value of US$8.5 million per year, considering only five fisheries.

# REFERENCES

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M., 2008. Economic valuation for the conservation of marine biodiversity. Mar. Pollut. Bull. 56, 386–396. https://doi.org/10.1016/j.marpolbul.2007.11.013

Bell, T.W., Cavanaugh, K.C., Reed, D.C., Siegel, D.A., 2015. Geographical variability in the controls of giant kelp biomass dynamics. J. Biogeogr. 42, 2010–2021. https://doi.org/10.1111/jbi.12550

Cavanaugh, K.C., Reed, D.C., Bell, T.W., Castorani, M.C.N., Beas-Luna, R., 2019. Spatial variability in the resistance and resilience of giant kelp in southern and Baja California to a multiyear heatwave. Front. Mar. Sci. 6, 1–14. https://doi.org/10.3389/fmars.2019.00413

Cavanaugh, K.C., Siegel, D.A., Kinlan, B.P., Reed, D.C., 2010. Scaling giant kelp field measurements to regional scales using satellite observations. Mar. Ecol. Prog. Ser. 403, 13–27. https://doi.org/10.3354/meps08467

Cavanaugh, K.C., Siegel, D.A., Reed, D.C., Dennison, P.E., 2011. Environmental controls of giant-kelp biomass in the Santa Barbara Channel, California. Mar. Ecol. Prog. Ser. 429, 1–17. https://doi.org/10.3354/meps09141

Checkley, D.M., Barth, J.A., 2009. Patterns and processes in the California Current System. Prog. Oceanogr. 83. https://doi.org/10.1016/j.pocean.2009.07.028

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R.G., Sutton, P., Van Den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260. https://doi.org/10.1038/387253a0

Dayton, P.K.P., 1985. Ecology of kelp communities. Annu. Rev. Ecol. Syst. 16, 215–245.

Domeier, M., 2001. Giant Sea Bass. California's Mar. Living Resour. A Status Rep. 209–211.

Edwards, M.S.M., 2004. Estimating scale-dependency in disturbance impacts: El Niños and giant kelp forests in the northeast Pacific. Oecologia.

Edwards, M.S.M., Estes, J.A., 2006. Catastrophe, recovery and range limitation in NE Pacific kelp forests: a large-scale perspective. Mar. Ecol. Prog. Ser. 320, 79–87. https://doi.org/10.3354/meps320079

Guenther, C., Lenihan, H., Grant, L., 2012. Trophic cascades induced by lobster fishing are not ubiquitous in Southern California kelp forests.

Hamilton, S.L., Caselle, J.E., 2015. Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forests. Proc. R. Soc. B-BIOLOGICAL Sci. 282. https://doi.org/10.1098/rspb.2014.1817

Jensen, J.R., Estes, J.E., Tinney, L., 1980. Remote sensing techniques for kelp surveys. Photogramm. Eng. Remote Sens. 46, 743–755.

Lafferty, K.D.K., 2004. Fishing for lobsters indirectly increases epidemics in sea urchins. Ecol. Appl. 14, 1566–1573. https://doi.org/10.1890/03-5088

Lange, G.M., Jiddawi, N., 2009. Economic value of marine ecosystem services in Zanzibar: Implications for marine conservation and sustainable development. Ocean Coast. Manag. 52, 521–532. https://doi.org/10.1016/j.ocecoaman.2009.08.005

Love, M.S., Caselle, J.E., Van Buskirk, W., 1998. A severe decline in the commercial passenger fishing vessel rockfish (Sebastes Spp.) catch in the Southern California Bight, 1980-1996. Calif. Coop. Ocean. Fish. Investig. Reports 39, 180–195.

Macaya, E.C., Zuccarello, G.C., 2010. DNA barcoding and genetic divergence in the giant kelp macrocystis (laminariales). J. Phycol. 46, 736–742. https://doi.org/10.1111/j.1529-8817.2010.00845.x

McClatchie, S., 2014. Oceanography of the Southern California Current System Relevant to Fisheries, in: Regional Fisheries Oceanography of the California Current System. Springer Netherlands, pp. 13–60. https://doi.org/10.1007/978-94-007-7223-6_2

Pendleton, L., Rooke, J., 2010. Understanding the Potential Economic Value of SCUBA Diving and Snorkeling.

Schiel, D., Foster, M., 2015. The Biology and Ecology of Giant Kelp Forests.

Schroeder, D.M., Love, M.S., 2002. Recreational fishing and marine fish populations in california 43, 182–190.

Tegner, M.J., Dayton, P.K., 2000a. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

Tegner, M.J., Dayton, P.K., 2000b. Ecosystem effects of fishing in kelp forest communities. ICES J. Mar. Sci. … 57, 579–589. https://doi.org/10.1006/jmsc.2000.0715

Tegner, M.J., Dayton, P.K., 1981. Population Structure, Recruitment and Mortality of Two Sea Urchins (Strongylocentrotus franciscanus and S. purpuratus) in a Kelp Forest. Mar. Ecol. Prog. Ser. 5, 255–268. https://doi.org/10.3354/meps005255

Wilmers, C.C., Estes, J.A., Edwards, M., Laidre, K.L., Konar, B., 2012. Do trophic cascades affect the storage and flux of atmospheric carbon? An analysis of sea otters and kelp forests. Front. Ecol. Environ. 10, 409–415. https://doi.org/10.1890/110176

# TABLES

Table 2.2.1. Economically important species of invertebrate and fish closely associated with the kelp forest ecosystem.

| **Taxonomy group** | **Common name** | **Scientific name** |
|---|---|---|
| Invertebrate | Abalone | *Haliotis spp.* |
| Invertebrate | Purple Sea Urchin | *Strongylocentrotus purpuratus* |
| Invertebrate | Red Sea Urchin | *Mesocentrotus franciscanus* |
| Invertebrate | Spiny Lobster | *Panulirus interruptus* |
| Fish | California Sheephead | *Semicossyphus pulcher* |
| Fish | Giant Sea Bass | *Stereolepis gigas* |

Table 2.2.2. Fishery Management Areas (FMA) for commercial fisheries in both geographic regions; 10 × 10-minute grid blocks by California Department Fish and Wildlife (U.S.) and fishery concession areas by Mexican Fisheries Management Agency-CONAPESCA (Mexico).

| Country | FMA (count) | Mean (Km²) | Max (Km²) | Min (Km²) | SD | Var |
|---|---|---|---|---|---|---|
| Mexico | 78 | 338.95 | 5379.00 | 1.10 | ±875.38 | 766283.27 |
| U.S. | 101 | 191.10 | 289.23 | 0.87 | ±94.06 | 8847.05 |
| Total | 179 | 255.89 | 5379.00 | 0.87 | ±586.27 | 343715.30 |
| T-Test |  | 0.1250* |  |  |  |  |

Table 3. Summary of regression analyses on 10-year mean fishery production (kg/km²) and percentage of giant kelp cover within the Fishery Management Areas (FMA).

| Fishery | N | $R^2$ | P | L.R. Equation |
|---|---|---|---|---|
| Spiny lobster | 105 | 0.1116 | 0.334 | $y = 42.537x + 27.098$ |
| Purple Sea Urchin | 118 | 0.829 | 0.911 | $y = 735.95x + 74.331$ |
| Red Sea Urchin | 119 | 0.806 | 0.898 | $y = 1768.8x - 172.07$ |
| Abalone | 62 | 0.8345 | 0.913 | $y = 2339.5x + 344.02$ |
| Giant Sea Bass | 107 | 0.0054 | 0.073 | $y = 0.1354x + 0.6768$ |
| CA Sheephead | 36 | 0.0006 | 0.249 | $y = 0.6979x + 22.661$ |

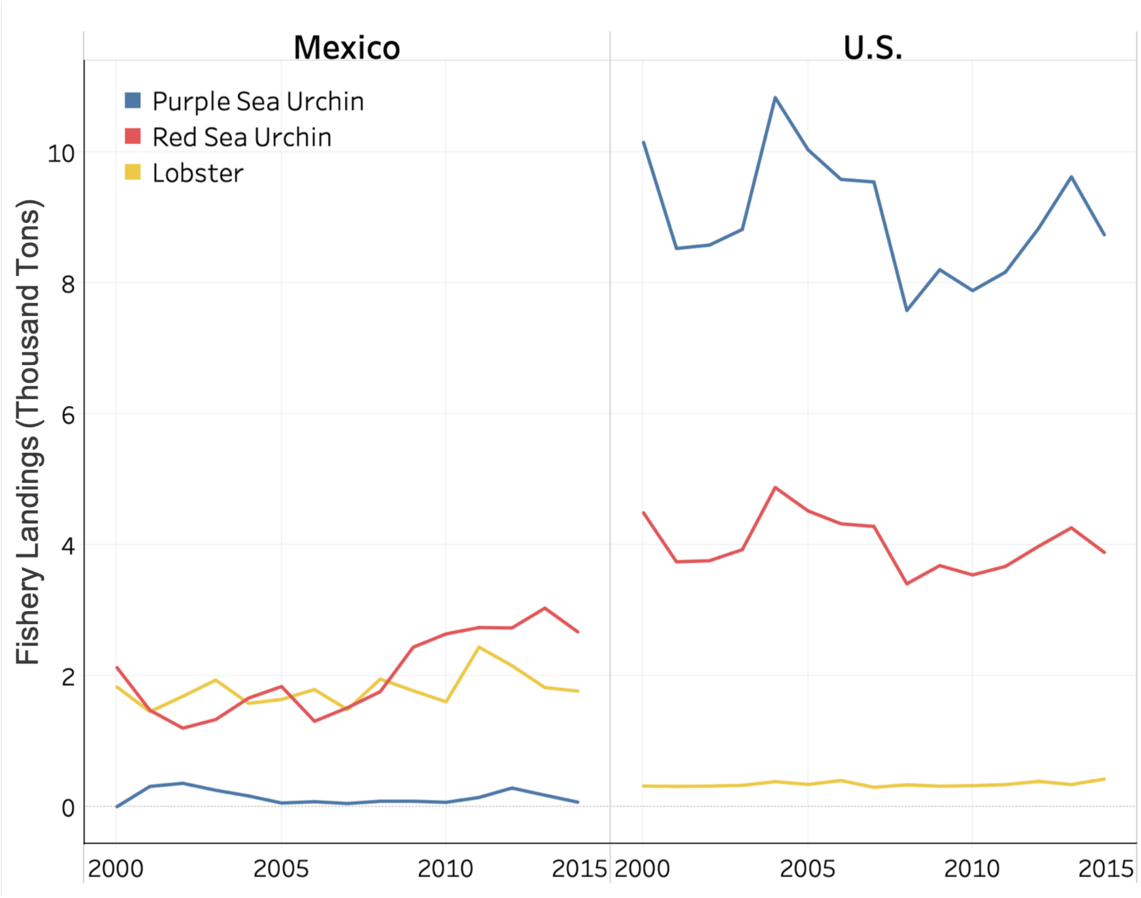

Figure 2.2.1. 2000-2015 Fishery landings (Thousand Tons/yr$^{-1}$) of three of giant kelp forest-associated species Spiny lobster (*Panulirus interruptus*), Red Sea Urchin (*Mesocentrotus franciscanus*), Purple Sea Urchin (*Strongylocentrotus purpuratus*) by country, Mexico and the United States (U.S.). Data source: CDFW (U.S.) and CONAPESCA (Mexico).

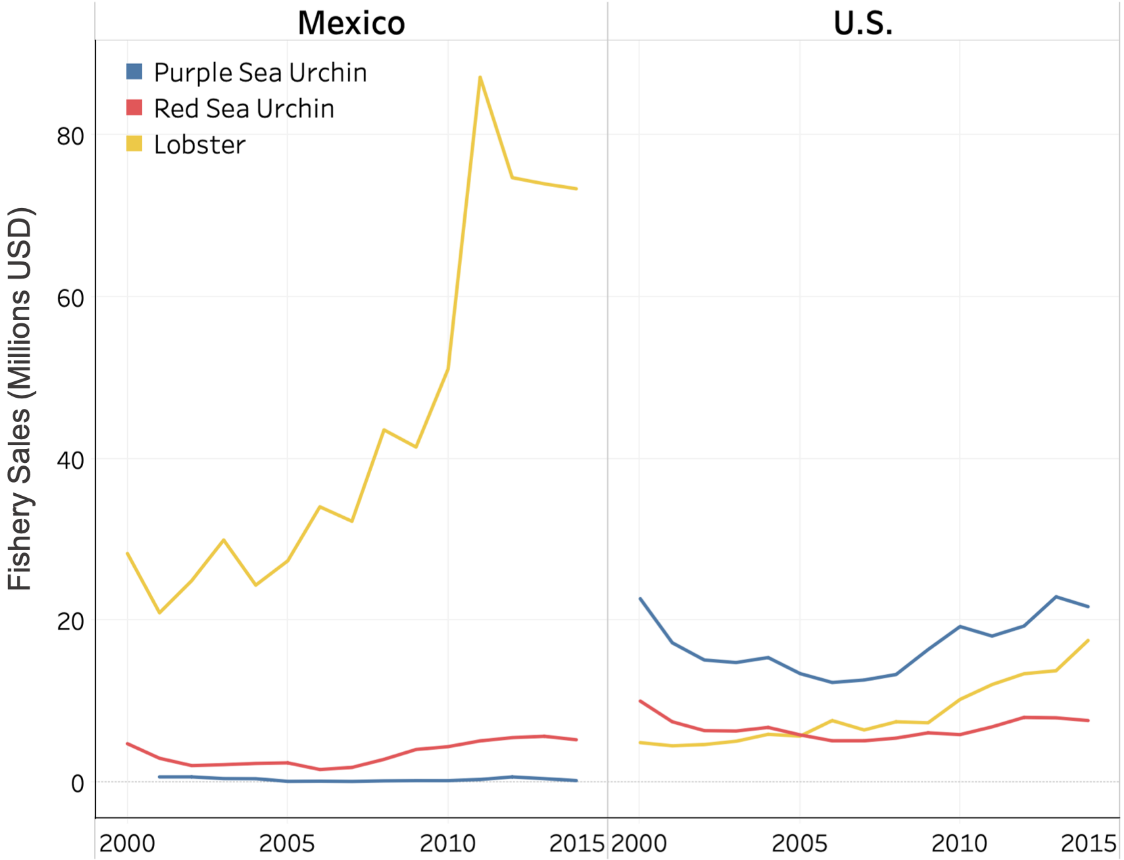

Figure 2.2.2. 2000-2015 Fishery Sales (Millions USD/yr$^{-1}$) of three of giant kelp forest-associated species Spiny lobster (*Panulirus interruptus*), Red Sea Urchin (*Mesocentrotus franciscanus*), Purple Sea Urchin (*Strongylocentrotus purpuratus*) by country, Mexico and the United States (U.S.). Data source: CDFW (U.S.) and CONAPESCA (Mexico).

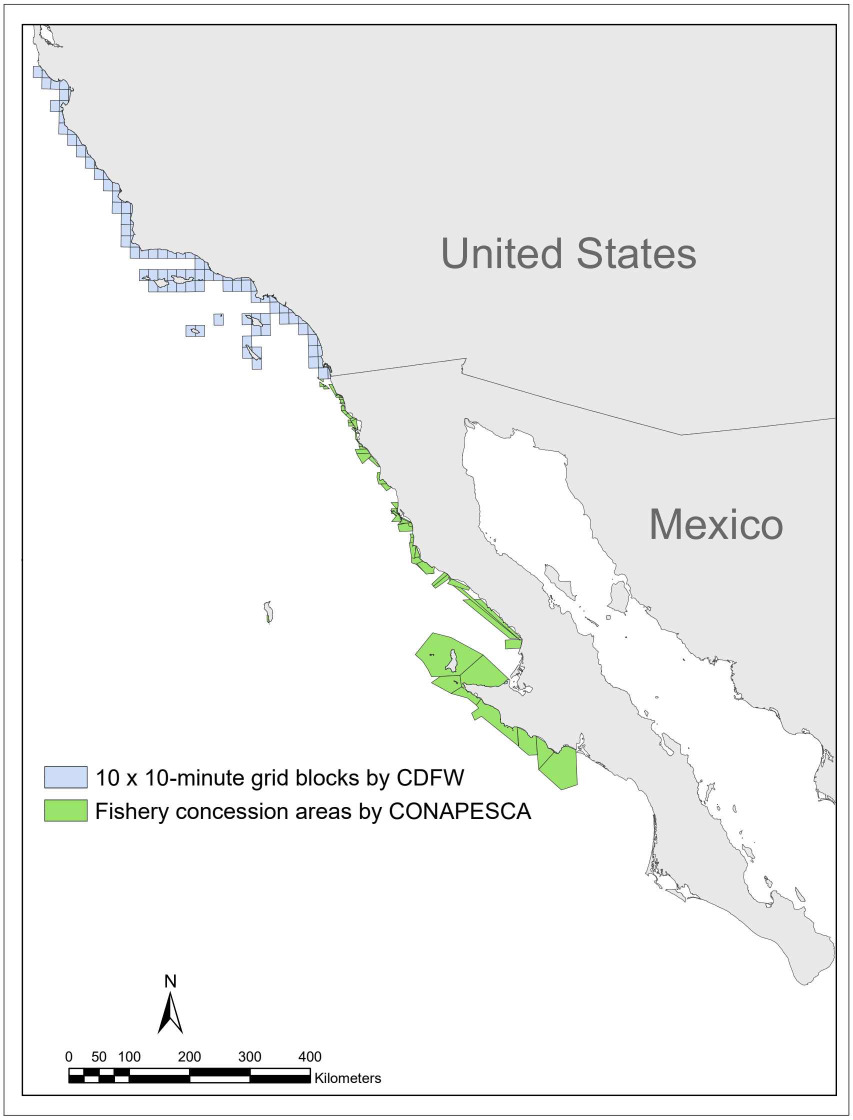

Figure 2.2.3. Fishery Management Areas (FMA) for commercial fisheries in both geographic regions; 10x10-minute grid blocks by California Department Fish and Wildlife (U.S.) and fishery concession areas by Mexican Fisheries Management Agency-CONAPESCA (Mexico).

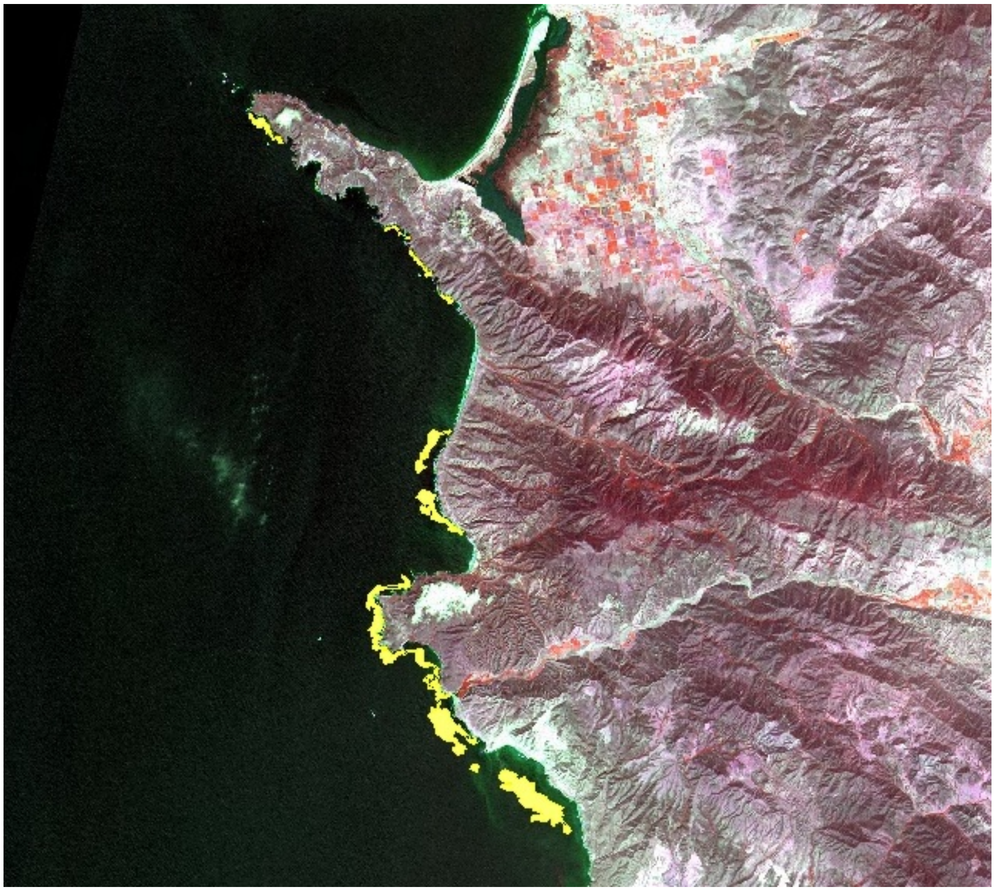

Figure 2.2.4. Landsat 5 Thematic Mapper image displaying the kelp cover in a small section of the study area; south of Bahia Todos Santos, Ensenada, Mexico, (Fall 2008).

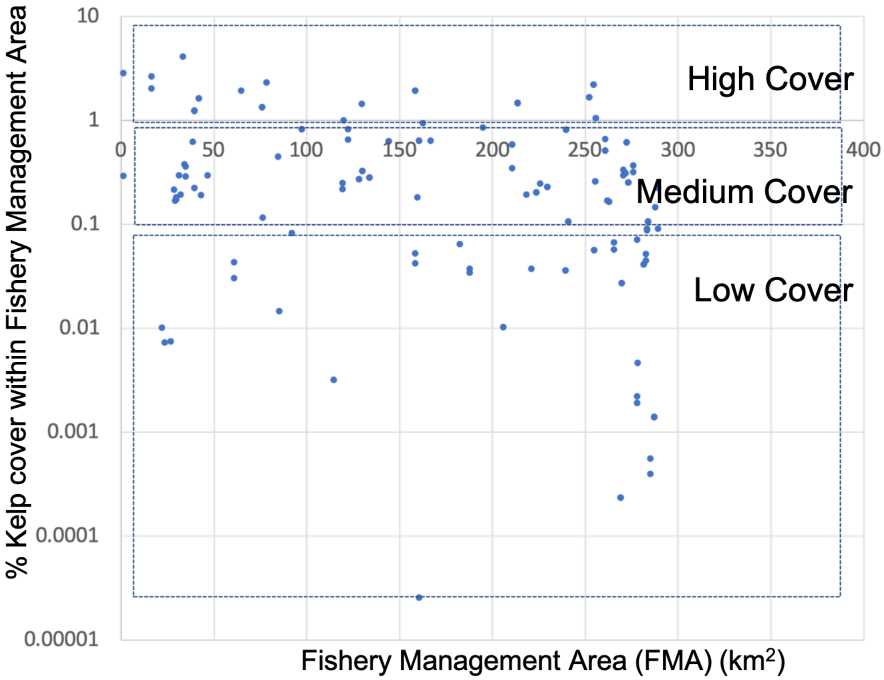

Figure 2.2.5. Percentage of kelp cover categories within the Fishery Management Areas (FMA); High (< 0.1%), Medium (0.1 – 1.0), Low (> 1.0%).

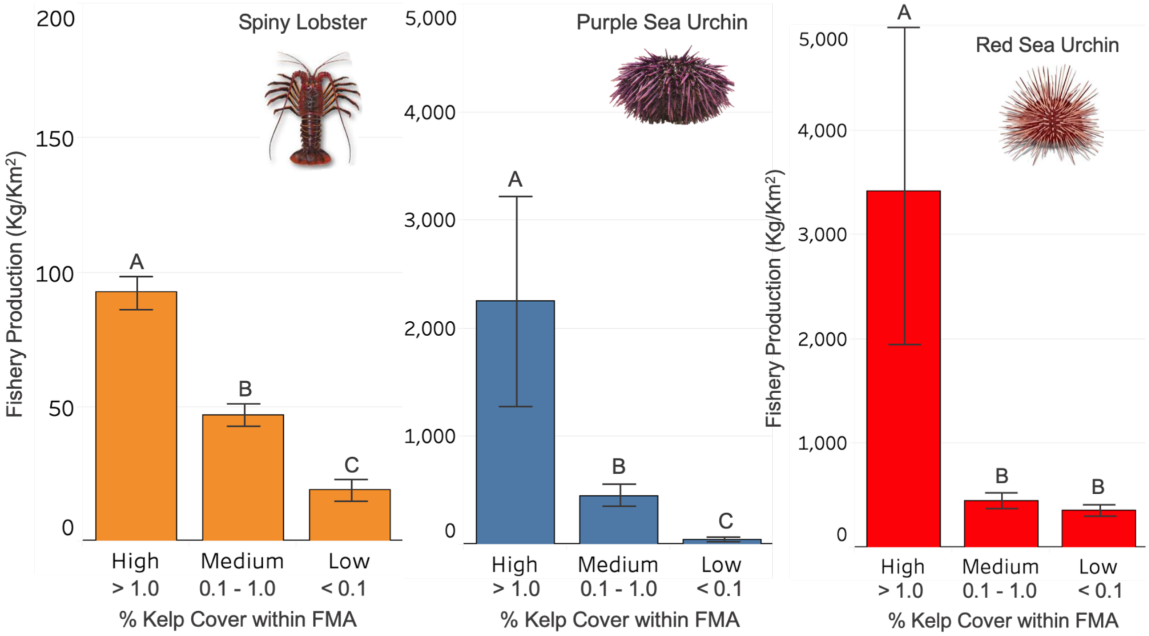

Figure 2.2.6. 10-year (2008-2017) average fishing production (Kg/Km²) according to the kelp cover size within the FMA; spiny lobster (*Panulirus interruptus*), purple sea urchin (*Strongylocentrotus purpuratus*), red sea urchin (*Mesocentrotus franciscanus*). Data are presented as mean ±S.E.M. where bars sharing a letter are not significantly different from one another (ANOVA post hoc P< 0.05.).

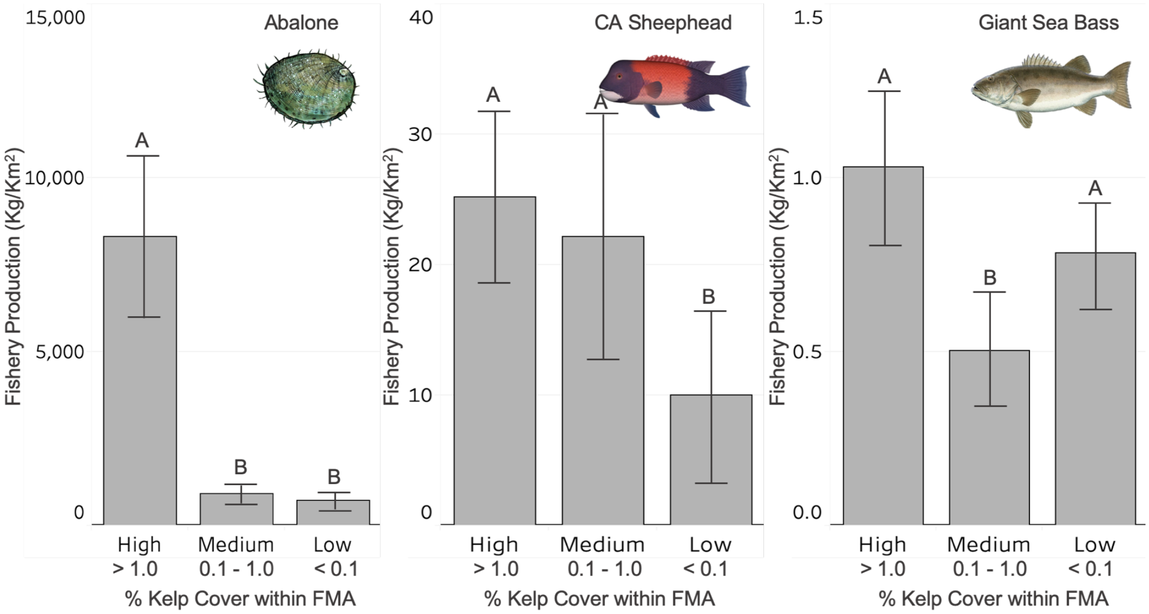

Figure 2.2.7. 10-year (2008-2017) average fishing production (Kg/Km²) according to the kelp cover size within the FMA; abalone (*Haliotis* spp.), California sheephead (*Semicossiphus pulcher*), giant sea bass (*Stereolepis gigas*). Data are presented as mean ±S.E.M. where bars sharing a letter are not significantly different from one another (ANOVA post hoc $P< 0.05$.).

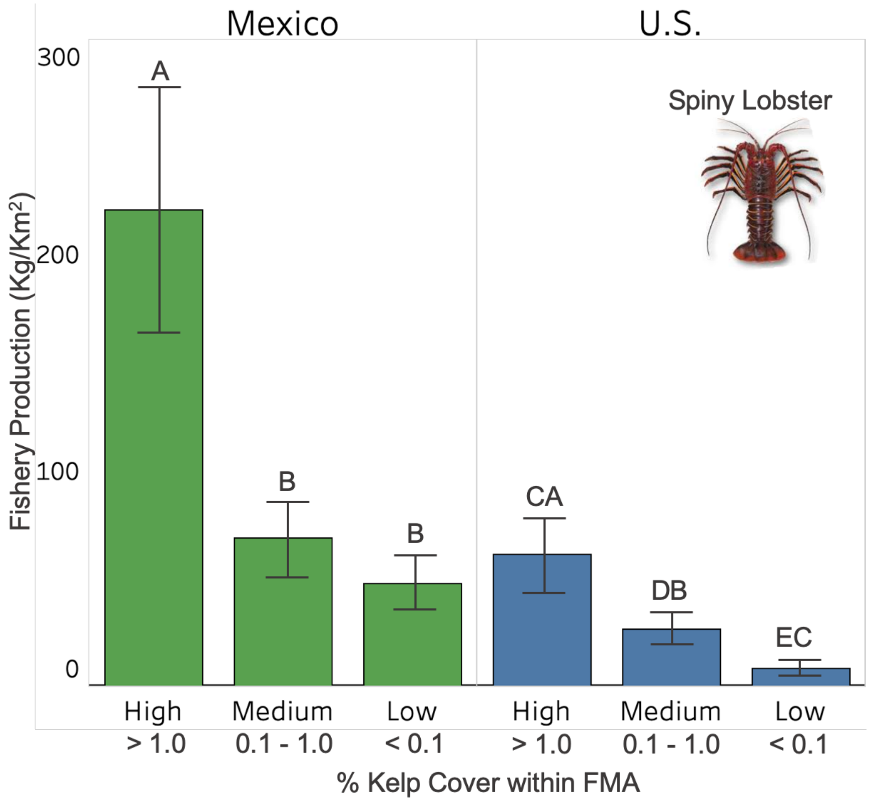

Figure 2.2.8. Spiny lobster (*Panulirus interruptus*) 10-year (2008-2017) average fishing production (Kg/Km²) according to the kelp cover size within the FMA by country, the U.S. and Mexico. Data are presented as mean ±S.E.M. where bars sharing letter are not significantly different from one another; first letter= within country, second letter= between countries (Two-way ANOVA, $P< 0.05$.).

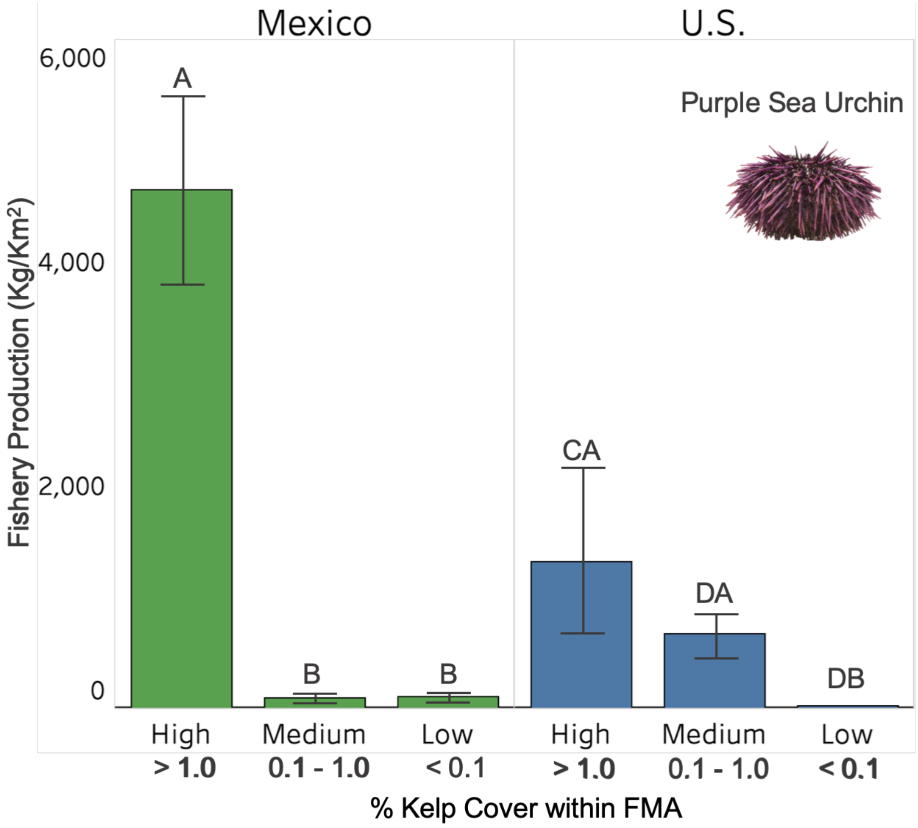

Figure 2.2.9. Purple sea urchin (*Strongylocentrotus purpuratus*) 10-year (2008-2017) average fishing production (Kg/Km²) according to the kelp cover size within the FMA by country, the U.S. and Mexico. Data are presented as mean ±S.E.M. where bars sharing letter are not significantly different from one another; first letter= within country, second letter= between countries (Two-way ANOVA, $P< 0.05$.).

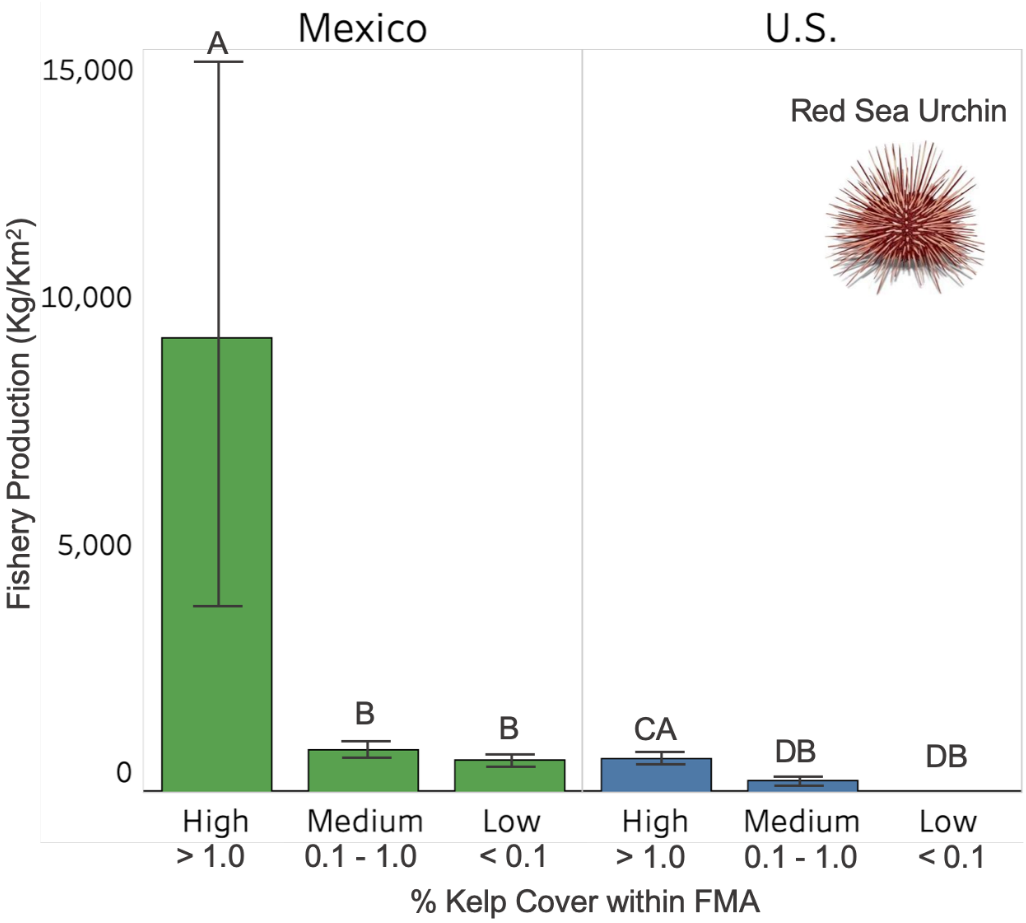

Figure 2.2.10. Red sea urchin (*Mesocentrotus franciscanus*) 10-year (2008-2017) average fishing production (Kg/Km²) according to the kelp cover size within the FMA by country, the U.S. and Mexico. Data are presented as mean ±S.E.M. where bars sharing letter are not significantly different from one another; first letter= within country, second letter= between countries (Two-way ANOVA, $P < 0.05$.).

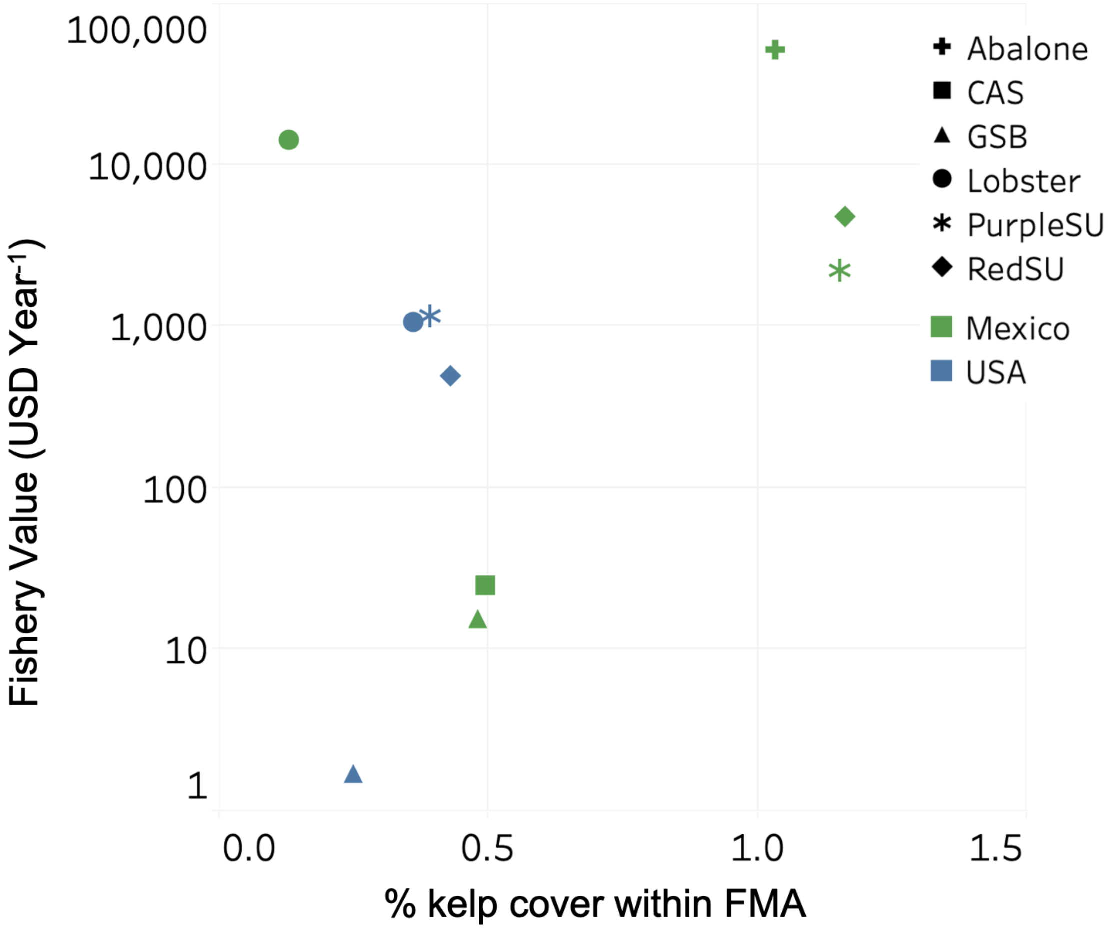

Figure 2.2.11. Relationship between economic value (USD/yr$^{-1}$) of 10-year average fishery production (2008-2017) considering fishery sales alone and the percentage of giant kelp cover within the FMA by country, the U.S. and Mexico.

# CHAPTER 3:

## Mexico-California binational initiative of kelp forest ecosystems and fisheries.

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Initiative

# Mexico-California Bi-National Initiative of Kelp Forest Ecosystems and Fisheries

White Paper for the Environmental Working Group of the UC-Mexico Initiative

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# Table of Contents

## Abstract

The coastal forests formed by the giant kelp *Macrocystis pyrifera* are iconic and primary habitats distributed discontinuously from central Baja California (Mexico) to central California (USA). The giant kelp creates a biogenic habitat that supports high levels of species diversity and productivity in the region, acting as a refuge, nursery and food provider for many species.

Kelp forests provides ecosystem services to humans worth billions of dollars globally. These services include food and natural products, chemical products, recreational and commercial fisheries, ecotourism opportunities, cultural value, and nutrient cycling. Coastal human populations rely on many of these ecosystem services.

Beyond its economic benefits, giant kelp, together with the species that inhabit the kelp forests, play a significant role in climate control by regulating carbon flows, acting as a reserve and sink for carbon dioxide on living tissue, and facilitating the burial of carbon in sea bed sediments. Giant kelp and the biological communities that it supports will likely react to climatic and non-climatic changes in complex and unexpected ways.

In California and Baja California, giant kelp forests can be expected to contract in their southern extent due to warming waters, reductions in nutrient availability, increasing wave disturbance and grazing by warm-water herbivores. In ecosystems shared between nations, such as kelp forest, the actions taken by one nation invariably affect the other. Effective management of such systems therefore requires strong cooperation.

### What is the problem? What are the critical issues?

The United States of America (USA) and Mexico together account for more than 2,600 km of coastline in the temperate sea of the Northeastern Pacific, which hosts a huge diversity of species ranging from locally resident populations important for sustaining food webs, to large predators and other mobile organisms that cross the national borders regularly. At least 220 species of macroalgae (Murray and Littler 1981), 3,000 species of marine macroinvertebrates (Cadien and Lovell 2015), 519 species of fish (Horn et al. 2006), 29 species of marine mammals (Daugherty 1985) and five species of marine reptiles (Beltz 2006) are distributed throughout the temperate region of Northeastern Pacific. This region is delimited by the northern border of Washington (USA) and the southern end of the Baja California Peninsula (Mexico). Conservation of marine biological diversity along this broad geographical region is important not only for maintaining the demographic and genetic flow among populations on both sides of the border, but also to maintain critical ecosystems services for coastal human populations.

The marine territory off the coast of California and Baja California is part of the California Current System (CCS), which is one of the five most productive marine ecosystems on the planet (Fig. 1). The CCS has a high productivity as a result of temperate water movement towards the equator as well as favorable winds for coastal upwellings, which together generate an offshore transport of surface waters and advection of cold and nutrient-rich waters to the surface (Checkley and Barth 2009). Throughout the CCS, there is a diversity of oceanographic features that lead to a variety of habitat types within the system (Spalding et al. 2007; Greene et al. 2013; Morgan et al. 2015) (Fig. 1). Among them, coastal forests formed by the giant kelp *Macrocystis pyrifera* are primary habitats that support the high diversity and productivity of the region, acting both as nursery and food providers for many species.

Giant kelp forests can be considered the submerged counterparts of rain forests. They are among the most species-rich communities in temperate seas and among the most productive ecosystems on Earth (Schiel and Foster 2015; Reed and Brzezinski 2009). Kelp forests are a complex three-dimensional habitat structured by a second layer of understory macroalgae attached to the sea bottom (Dawson et al. 1960). They create biogenic habitats that provide refuge for numerous species, including many of economic importance for fisheries (Foster and Schiel 1985; Hernández-Carmona et al. 1989; Parnell et al. 2010a; Torres-Moye et al. 2013).

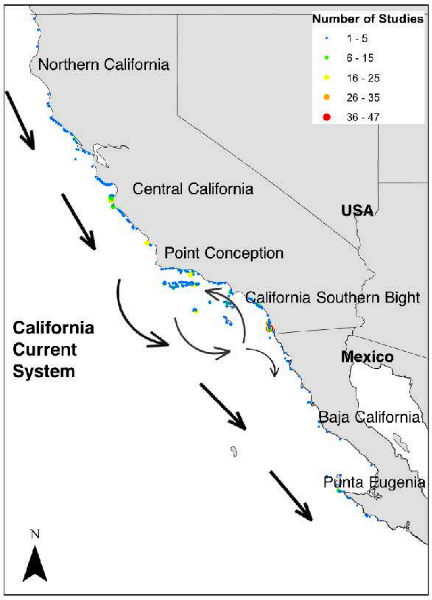

Figure 1. Geographic localization and main oceanographic features in the California Current System, including study sites and study effort in number of peer-review papers of the kelp forest ecosystem across the California (USA) and Baja California (Mexico) coast.

Historically, the latitudinal range of giant kelp on the west coast was thought to extend from Sitka, Alaska, at 57°N to Bahía Magdalena, Mexico, at 24°N, as its southernmost limit (Setchell and Gardner 1925; Dawson et al. 1960; Macaya and Zuccarello 2010; Schiel and Foster 2015) (Fig. 1). Several variables acting at different scales and different life history stages of the giant kelp control those distribution limits. Temperature and its relationship with nutrient availability, together with the availability of hard substrate, are among the most important (Jackson 1977; Hernandez-Carmona et al. 2001; Edwards and Hernández-Carmona 2005; Edwards and Estes 2006).

Giant kelp is an "ecosystem engineer" (sensu Jones et al. 1994) and generally the dominant species of the community, accounting for a disproportionately large share of the biomass in the system (Dayton 1985; Dayton et al. 1992; Steneck et al. 2002; Rassweiler et al. 2008; Reed et al. 2008; Schiel and Foster 2015). Giant kelp can grow up to 60 m in length at a maximum rate of 60 cm per day, with densities sometimes exceeding 1.5 adult plants/$m^2$ with more than 10 stipes/$m^2$, which explains its high contribution of biomass relative to other species in the community (Carr 1994; Edwards 2004; Reed et al. 2009). The abundance of biomass of giant kelp is very dynamic in space and time as a result of its seasonal variations, grazing, storms, episodic oceanographic events and long-term climate changes (Dayton and Tegner 1984; Hernández-Carmona et al. 1989, 2001; Reed et al. 2011; Schiel and Foster 2015).

Global climate plays a vital role in determining the distribution, structure, function, and biodiversity of giant kelp forests. As a result of rapid atmospheric climate change, coastal water temperature, nutrient availability, pH, wave disturbance, and sea level are all changing or forecast to change in coming decades (IPCC 2013, 2014). Overlaid on these large-scale stressors are other local stressors on giant kelp forests resulting from coastal development and urbanization, such as runoff of sediments and nutrients, overfishing, and invasive species. Giant kelp and the biological communities that it supports will likely react to climatic and non-climatic changes in complex and unexpected ways (Crain et al. 2008; Johnson et al. 2011). In California (USA) and Baja California (Mexico), giant kelp forests may be expected to contract in their southern extent due to warming waters, reductions in nutrient availability, and increases wave disturbance and grazing by warm-water herbivores (Ridgway and Hill 2012). Changes in sea level are harder to predict but could lead to increases or decreases in available habitat depending on nearshore bathymetry and coastal management (e.g., shoreline armoring). We should also expect direct and indirect effects of climate change on kelp forest organisms. Members of kelp forest communities, especially calcifying organisms or those existing near their thermal limits, may change in abundance and distribution in response to warming and ocean acidification (OA). Changes in the abundance and distribution of giant kelp will have indirect effects on fishes and invertebrates that depend on giant kelp for shelter or food, as well as competing species of algae that thrive in the absence of giant kelp. Ecological surprises such as complex, cascading interactions, the immigration of novel species, or unexpected local adaption to climate stressors are very likely and challenge our ability to accurately predict the future of giant kelp forests in a changing climate.

In ecosystems shared between nations, such as kelp forest, the actions taken by one nation invariably affect the other. Effective management of such systems therefore most commonly one that involves strong cooperation. The research benefits realized from international initiatives are as essential to scientific progress as they are to environmental preservation. Understanding how climate change will impact nearshore ecosystems, such as the large kelp forests along the California and Baja California coasts, will require geographically extensive assessments of these effects and solid understanding of the ecology and oceanography of this region.

## Impacts of Kelp Forests on Human Welfare

Early in the last century (1910) the population of California was 2.4 million, while Baja California had only 9,760 inhabitants. By the end of 2015, the population of California increased more than 11-fold to 39.14 Million and the population of Baja California more than 300-fold to 3.15 million (US Census Bureau; Mexico National Institute of Statistics and Geography-INEGI). This population growth significantly exceeded the growth rate of total population in the respective countries, due to a mixture of migration, economic expansion, and political developments (Rubin-Kurtzman et al. 1996). Population growth increased pressure on local ecosystem services, and signs of over-exploitation have been documented in the region (Clough-Riquelme and Bringas-Rábago 2006; Shaw et al. 2011). Resources that sustain quality of life have shown signs of deterioration, including air and fresh water (Cramer 1998; Mumme 1999). For example, overfishing has led to major declines in some fisheries in this region (Tegner and Dayton 2000; Schroeder and Love 2002; Erisman et al. 2011).

Kelp forests provide ecosystem services to humans worth billions of dollars globally (Costanza et al. 1997, 1998; Carr and Reed 2016). These valuable services include food and natural products (Leachman 1921; Mead 1976), chemical products (Neushul 1987), recreational and commercial fisheries (Dayton et al. 1998; Tegner and Dayton 2000), ecotourism opportunities (Pendleton and Rooke 2006), cultural value (Leachman 1921), wave and current attenuation (Gaylord et al. 2007; Garden and Smith 2015), and nutrient cycling (Jackson 1977; Wilmers et al. 2012). As ecosystem engineers, kelps transform marine habitats by controlling sediment dynamics, reducing the turbulent mixing beneath the canopy and controlling the water flow. Altogether, this causes fairly uniform vertical currents within the kelp forest with less shear than outside, which results in shoreline protection (Jackson 1983; Eckman et al. 1989; Rosman et al. 2007; Stewart et al. 2009; Garden and Smith 2015).

Since the early 1900s the harvest of giant kelp has been an important source of food, chemicals, fertilizers, and alginates, and more recently kelp has been used as animal feed (Schiel and Foster 2015). Harvest occurred along the coast of California and Baja California, although the major effort was concentrated from Santa Barbara to San Diego and in the northern Baja California region, from Playas de Tijuana to El Rosario (Robledo 1998; Bedford 2001; Casas-Valdez et al. 2003). Kelp harvest became the largest industry ever created from the processing of marine plants in the United States (Neushul 1987). Global demand for alginate has continued in recent decades and the industry has an estimated value of $ 318 million, but the large-scale harvest of giant kelp in California and Baja California ended in 2006 due to increased production costs and the opening of foreign markets (Bixler and Porse 2010; Schiel and Foster 2015). Following the closure of the industrial harvest of giant kelp, an artisanal harvest has remained on both sides of the border to produce feed for abalone farms (Schiel and Foster 2015).

Aesthetic characteristics and the ecological significance of kelp forests attract a large number of visitors who participate year-round in a variety of recreational activities such as diving, snorkeling, kayaking, and boating. Tourism and recreation are one of the main economic sectors for both California and Baja California, contributing 22% of the gross state product of California (Kildow and Colgan 2005) and up to 12% for Baja California (SECTURE 2000). Activities related to the sea in California are estimated to involve up to 12.2 million people annually (Pendleton and Rooke 2006), of which kelp forest-related activities are a significant part (Schiel and Foster 2015). Snorkeling and diving are two important marine recreational activities in California, in 2000 alone, there were an estimated 1.38 million dives and 3.82 million snorkeler-days (Leeworthy and Wiley 2001). In 2000, estimates put the annual value of scuba diving in California at $20-69 million and the annual value of snorkeling activities at $19-114 million in 2000 (Pendleton and Rooke 2006). Other marine recreational activities potentially related to the use of kelp forest ecosystems, such as kayaking, wildlife viewing, boating, and bird watching, account for another $72.7 million per year (Pendleton and Rooke 2006).

Reliable estimates of revenues from recreational activities related to kelp forests in Baja California are not available. The small number of service providers, low human populations and limited promotion of these activities suggest that revenues are lower in Baja California than in California. Nevertheless, the economic potential for marine recreational activities in Baja California is well understood and potentially large (GEBC 2015a). The gross value of tourism for Baja California in 2001 was $2.59 billion (GEBC 2015b) and recreational activities generated $3.79 million.

Fisheries associated to kelp forest provide economic and social support for the region. Throughout the CCS, several species of invertebrates such as abalone (*Haliotis* spp.), lobster (*Panulirus interruptus*), and sea urchins (*Strongylocentrotus* spp.), in addition to species of fish including giant sea bass (*Stereolepis gigas*), white sea bass (*Atractoscion nobilis*), yellowtail (*Seriola lalandi*), rockfishes (*Sebastes* spp.), kelp bass (*Paralabrax clathratus*), and California sheephead (*Semicossyphus pulcher*), are caught both recreationally and commercially, from shore or at sea (Love et al. 2002). It is impossible to isolate the effects of kelp forests versus other habitats on these fisheries because most species are not exclusive to one habitat type. California commercial fishing generated around $113 billion in sales in 2008, while the recreational fishery generated $106 billion in sales, including $55 million for the issue of fishing licenses (CDFG 2009). Commercial fishing generated 1.5 million jobs, and the recreational sector accounted for another 534,000 (NOAA 2008). Commercial fishery revenues in Baja California currently are much lower. Approximately $27 million and 30,628 direct jobs (SEPESCA 2015) were generated by these activities and about $127,000 were collected from sales of sport fishing permits in 2008 (Sosa-Nishizaki et al. 2013).

Beyond its economic benefits, giant kelp, together with the species that inhabit the kelp forests, may play a significant role in climate control by regulating carbon flows, acting as a reserve or sink for carbon dioxide on living tissue, and facilitating the burial of carbon in sea bed sediments. By increasing kelp biomass, atmospheric carbon dioxide could potentially be reduced and sequestered in a reservoir where it could remain for long periods of time by exporting drifting algae to the deep sea (Wilmers et al. 2012). However, Reed and Brzezinski (2009) argue that, unlike other coastal ecosystems, kelp forests contribute little to carbon sequestration because the vast majority of kelp carbon is rapidly degraded and re-mineralized, and the main storage of kelp carbon is in the standing biomass.

## Kelp forests in a Binational Context

The equator-ward flow of the California current in the CCS and its coastal countercurrents promote the transport of larvae and early-stage individuals throughout the region and influence the distribution of the adult stages of many species (Horn et al. 2006). Several studies have documented the relationship between species populations on the two sides of the USA-Mexico border in terms of distribution (Horn et al. 2006), larval dispersal (Cowen 1985; Funes-Rodriguez et al. 2015), migration (Aalbers and Sepulveda 2015) and genetic connectivity (Iacchei et al. 2013; Munguía-Vega et al. 2015; Johannson et al. 2015). The white sea bass (*Atractoscion nobilis*) is a good example of a trans-boundary resource with documented population connectivity across the border that supports both recreational and commercial fisheries (Vojkovich and Reed 1983; Aalbers and Sepulveda 2015; Romo-Curiel et al. 2016). Historically, the USA fishing fleet has been larger than the Mexican fleet, in terms of both vessels and landings within Mexican waters. Reports show that in some years up to 80% of the total landings by the commercial fleet of California were from in Mexican waters (Vojkovich and Reed 1983). After a decline in commercial catches in the 1960s, restoration strategies were adopted in California with little success. Research interest on both sides of the border has fostered a new effort to determine the population dynamics of the species across its entire distribution (Aalbers and Sepulveda 2015; Romo-Curiel et al. 2016).

Recent studies of the spiny lobster (*Panulirus interruptus*), one of the most important commercial fisheries in the region, showed high connectivity among populations along its distribution in the Pacific (Miller 2014). Genetic differentiations that have been found between some populations can be explained by coastal upwelling (Iacchei et al. 2013; Funes-Rodriguez et al. 2015). A similar pattern has also been observed in populations of barred sand bass (*Paralabrax nebulifer*) throughout the Pacific USA-Mexico region. Despite the decline of populations due to commercial fishing pressure in California and Baja California, there is a high degree of genetic diversity and genetic mixing (Erisman et al. 2011). These results suggest the existence of a single large population of barred sand bass in the Northeastern Pacific, reiterating the trans-national nature of marine species in the region (Paterson et al. 2015).

The following are some examples of studies that examine population connectivity and demographic connectivity across the California and Baja California borders for different taxa of kelp, invertebrates and fish.

1) Kelp. Several surface canopy-forming kelp species have distributions that encompass both California and Baja California. These are the giant kelp (*Macrocystis pyrifera*), elk kelp (*Pelagophycus porra),* and feather boa kelp (*Egregia menziesii).* Out of these three species, giant kelp is the most thoroughly studied. Empirical and theoretical studies of giant kelp dispersal (Gaylord et al. 2006; Hernández-Carmona et al. 2006; Reed et al. 2006), spatial analysis population analyses (Cavanaugh et al. 2014; Castorani et al. 2015), and molecular tools (Alberto et al. 2011) have improved our understanding of the propagule dispersal, patch and metapopulation dynamics, population genetics, and molecular ecology of this species. These studies suggest that spore transport by oceanographic currents is an important determinant of population and demographic connectivity among giant kelp patches (Alberto et al. 2011; Castorani et al. 2015; Johannson et al. 2015). While population connectivity depends primarily on the absolute number of dispersers between populations, demographic connectivity depends on the relative contribution to the growth rates of the population of dispersers and local recruitment (Lowe and Allendorf 2010). The spore dispersal between patches of kelp forests is not limited enough to prevent demographic connectivity, yet not broad enough to result in homogenous, panmictic populations (Gaylord et al. 2006; Reed et al. 2006; Alberto et al. 2011). Demographic connectivity can strongly determine the population dynamics of giant kelp, increasing the probability of colonization and persistence through time (Castorani et al. 2015).

2) Invertebrates. Kellet's whelk (*Kelletia kelletii*) is an abundant predator in the kelp forest ecosystem and an emerging fishery in California since 1979 (Hubbard 2008). Zacherl et al. (2003), using microchemistry in larval protoconchs and statoliths of Kellet's whelk, found that populations north and south of California's Point Conception showed a different chemical composition that might reflect differences in the population source providing recruits. Similarly, Torres-Moye (2012) examined the genetic diversity between island and coastal populations of the limpet *Megathura crenulata* and sea star *Patiria miniata* using the mitochondrial DNA control region. He suggests that the short larval duration of the *M. crenulata*, combined with intense harvest pressure, may limit the dispersal capabilities of this species, compared with the sea star *P. miniata.*

Studies of the sea star *Pisaster ochraceus* along the CCS (Vancouver Island to Punta San Carlos, Baja California) using mitochondrial DNA suggest that genetic homogeneity exists among populations, due to the transport of larvae along the CCS that coincides with the reproductive peak of this species (March to June), when the current has a strong southward flow (Fontana-Uribe 2005). Studies of the pink abalone (*Haliotis corrugata*) found a low to moderate genetic diversity at five locations of the northeastern Pacific of Mexico and the USA (Díaz-Viloria et al. 2009).

3) Fish. Many fish species have restricted movement when adults; however, for species with pelagic larvae ocean currents may disperse them over large distances—up to hundreds of kilometers (Kinlan and Gaines 2003; Freiwald 2012). California sheephead (*Semicossyphus pulcher*), kelp bass (*Paralabrax clathratus*), and kelp rockfish (*Sebastes atrovirens*) are some of the most abundant species throughout the trans-boundary region and are subject to commercial and recreational fisheries; however, their management and conservation are performed independently in each country.

The connectivity of California sheephead populations has been examined by recruitment, genetic analysis and ocean circulation patterns. Cowen (1985) use a combination of field counts and age-structure data to suggests that larval supply to populations in the Southern California bight is variable and relies on anomalous recruitment related with El Niño or La Niña events, with warm northward flow carrying the larvae of these and other species into the waters of California (Cowen 1985; Methot et al. 2004). Selkoe et al. (2007) used three different datasets including time series of larval abundance and microsatellite markers analysis to investigate whether California sheephead and kelp bass populations depend on Mexican populations. They found very localized population connectivity and very little exchange between California and Baja California populations. Bernardi et al. (2003), using DNA analysis, found the presence of population structure between northern and southern Baja California populations in some kelp-associated fish species like opaleye (*Girella nigricans*) and sargo (*Anisotremus davidsoni*), but no structure in others (*Halichoeres semicinctus* and *Semicossyphus pulcher*).

In sum, several approaches have been used to study connectivity along the California Current System, such as recruitment and ocean circulation patterns (Cowen 1985; Cowen et al. 2006; White et al. 2010), microchemistry (Simmonds et al. 2014; Zacherl 2005; Warner et al. 2005), and genetics (Palumbi 1995; Fontana-Uribe 2005; White et al. 2010; Torres-Moye 2012). Whilst some of the outcomes from these population connectivity studies show the importance of local fisheries management schemes, the majority suggest that regional management is the most appropriate strategy for future interventions.

## Theoretical Framework

The study of kelp forests along the California Current System (CCS) have had two very different histories. On the one hand, along the coast of California, a long history of fishing pressure (Tegner and Dayton 2000), continuous long-term scientific monitoring programs (Tegner and Dayton 1987; Foster et al. 2013; Kenner et al. 2013; Kushner et al. 2013), and more recently, networks of marine protected areas (Botsford et al. 2014), all highlight the large quantity of coastal human impacts, both positive and negative, on the ecosystem. The investment of research effort along this coast makes giant kelp forests without question the most studied kelp system of the Northeastern Pacific, and may be globally (Schiel and Foster 2015). In contrast, the kelp forests off the coast of Baja California have received much less attention, both from large-scale fishery pressure, research monitoring initiatives and spatial protection schemes. For example, there is no equivalent marine protected area network along the Baja California coastline.

We conducted a systematic literature review of peer-reviewed papers to assess the state of scientific knowledge on the kelp forest ecosystem along the California and Baja California coastline. The review finds differences in study effort on the two sides of the border and identifies temporal and spatial trends between studies. We found more than 40 times more peer-reviewed papers on kelp forest ecosystem topics in California than in

Baja California. Research focusing on kelp forest ecosystems in California dates back to the 1940s (Andrew 1945), while for Baja California the pioneering studies began three decades later. The first publication on kelp forests in Baja California published by Mexican researchers appeared early in the 1970s (Guzmán del Próo et al. 1971). Out of a total of 236 articles in the review, only 9 peer-reviewed papers include sites on both sides of the border, highlighting the lack of studies taking a binational approach. Study sites in the region of Baja California and northern California stand out as the most recently documented. The best-documented kelp forests of the region, based on number of publications, are located in Southern California near Point Loma and La Jolla (Fig. 1).

Ecological comparisons between kelp forest communities in California and Baja California has been challenging, as the majority of data collected from different monitoring programs are not standardized. However, seminal work by Edwards (2004) shows responses and impacts of the El Niño 1997-1998 from central California to its southernmost limit in Baja California. Existing monitoring programs range in taxonomic complexity from exhaustive lists including both conspicuous and cryptic fish, macroinverterbrates, and macroalgae (Vantuna Research Group, UABC), to programs that capture the majority of non-cryptic biodiversity (SDSU, Partnership for the Interdisciplinary Study of Coastal Oceans: PISCO, COBI-Stanford) and programs that focus on key species of economic or ecological importance (Reef Check CA, Channel Islands National Park Service: CINPS). Sampling effort (sites and years) also varies among programs.

Daily sea surface temperatures have been recorded at several locations along the California coast as part of the Shore Station Program, with temperature records going back nearly a century at the Scripps Institution of Oceanography Pier in southern California and Pacific Grove in central California. Paleo-climate records, mainly in the form of sediment cores from anoxic basins within the wide southern California shelf, extend our knowledge of climatic fluctuations within the CCS much further back in time (Schimmelmann and Lange 1996). Together, these records provide evidence that temperatures and productivity within the CCS have fluctuated greatly in the past, and that the ecology of pelagic ecosystems responds strongly to these fluctuations (McGowan et al. 2003; Di Lorenzo et al. 2013).

In contrast, the paleo-record for inner shelf benthos communities, such as kelp forests, is sparse or non-existent (Braje et al. 2009). However, cartographic and aerial photographic records extend our knowledge of kelp canopy coverage back to the beginning of the 20th century in some areas, with annual resolution in southern California available from the 1960s onward. Further, for benthic algae that do not produce a floating canopy at the surface, populations have been studied for the past several decades using *in situ* diver surveys such as those associated with the CINPS kelp forest monitoring program, San Diego State University, USGS kelp forest monitoring program at San Nicolas Island, the coordinated PISCO, California Reef Check, Santa Barbara Coastal Long Term Ecological Research program, and numerous independent academic research groups. Together, these activities have shown that benthic macroalgae and kelp canopy cover are highly sensitive to seasonal, inter-annual and decadal-scale fluctuations in oceanographic conditions within the CCS (Jackson 1977; Dayton et al. 1984, 1999;

Edwards 2004; Edwards and Estes 2006; Parnell et al. 2010b; Kenner et al. 2013; Bell et al. 2015). With this information, we can divide our framework of the bi-national kelp forest ecosystem into two periods:

**(a)** The system before and during the 1970's. The dynamic forcing of the CCS is closely related to large-scale decadal North Pacific climate modes such as the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO) (Di Lorenzo et al. 2008). These modes have been related to corresponding patterns in several biological time series, such as the alternating anchovy/sardine cycle within the CCS. Inter-annual and seasonal patterns of variability are superimposed onto these decadal climate modes (Sugihara et al. 2012). Positive El Niño Southern Oscillation years (ENSO) are associated with a deepened thermocline, warmer waters, and lower nutrients. Positive decadal climate modes magnify these effects of El Niño. For instance, there was a large positive shift in the PDO during the late 1970s that has been recognized as a North Pacific-wide regime shift, with profound declines in productivity and fish stocks within the CCS (McGowan et al. 2003; Holbrook et al. 1997; Chavez et al. 2003; Koslow et al. 2013).

Cool, dense waters beneath the thermocline are replete in inorganic nitrogen, the main limiting nutrient in the CCS for algal growth, while warmer waters above the thermocline are more depleted in nitrogen (Jackson 1977). Seasonal upwelling, forced by equatorward winds during spring and summer along the CCS, pumps sub-thermocline, cool nutrient-rich water up onto the shelf (Huyer 1983; Checkley and Barth 2009). However, the upwelled water is also low in oxygen and pH, thereby increasing the risks of hypoxia and acidification to coastal ecosystems (Nam et al. 2011). Since the coastal thermocline is depressed during positive phases of the PDO, seasonal upwelling provides only a limited nutrient subsidy during these periods and a concomitant El Niño tends to further limit subsidies.

The structure of the CCS changed during the regime shift of the late 1970s (Miller et al. 1994). For instance, zooplankton volumes decreased in a step manner across this shift (McGowan et al. 2003) and the CCS has freshened and warmed since that time (Bograd et al. 2003; Di Lorenzo et al. 2005). Concomitant increases in the stratification of coastal waters, which decrease mixing of nutrient rich sub-thermocline waters with nutrient-depleted surface waters (Bograd et al. 2003), and subsequent decreases in oxygen content within the surface waters were also observed during this shift (Bograd et al. 2008).

**(b)** The system after the 1970's**.** Major secular trends have been observed since the regime shift of the 1970s. These include further warming and freshening of the CCS, decreasing oxygen and pH, a thickening and shoaling of the oxygen minimum zone (a zone of low oxygen between 300 and 500 m deep off California), and rising sea levels. These trends are superimposed onto cyclical decadal ocean climate modes, and thus represent potential thresholds for potent regime shifts in the future.

Adding to this uncertainty is the likelihood that upwelling winds will increase with global warming, perhaps buffering the nutrient risk to coastal ecosystems such as kelp forests while further exacerbating hypoxia and OA (Bakun 1990; Rykaczewski and Dunne 2010). The degree to which humans have contributed to these secular trends has been the subject of much debate, but it is clear that warming and sea level rise will continue on a global scale (Stocker 2014). Storms, a major source of disturbance for kelp forests (Bell et al. 2015), may also continue to intensify as they appear to have done in the North Pacific in the latter half of the 20th century (Seymour et al. 1989; Graham and Diaz 2001).

Sea level will rise ~1 m by the end of this century, though recent evidence of ice instability and the risk of ice collapse in the West Antarctic Peninsula and the Greenland Ice Shelf suggest that global sea level could rise much faster (Dutton et al. 2015). On a local scale, sea level rise may cause giant kelp to migrate shoreward in order to track changes in light availability (Kinlan et al. 2005; Graham et al. 2007). In areas with insular kelp forests or where shorelines are reinforced to prevent coastal erosion, sea level rise may constrict the effective habitat area for giant kelp growth (Graham et al. 2007). In contrast, the impact of sea level rise on giant kelp distributions will probably be minimal on linear, unmodified coastlines (Graham et al. 2007).

Climate change will also cause indirect, habitat-mediated effects on kelp forest communities if warming does impact the abundance and distribution of giant kelp. It is likely that the nature and functioning of kelp forests will change, especially south of Point Conception (Parnell et al. 2010b). The distribution of giant kelp may even exhibit long-term contraction similar to short-term contractions observed during previous ENSOs (Ladah et al. 1999; Edwards and Hernández-Carmona 2005). While short-term patterns provide much needed insight into how the range limits of kelp forests are impacted by ENSO conditions, it is unclear how continued warming of eastern Pacific coastal waters will impact future range shifts in these forests that may result from ENSO events.

## Policy Responses and Challenges

Cooperative activities between the USA and Mexico take place under a number of treaties and agreements. Although there have been successful bi-national agreements regarding the use of common terrestrial resources between both countries, there are few examples of bi-national agreements regarding the management of marine resources.

The connectivity among many marine populations on the two sides of the USA-Mexico border highlights the importance of binational coordination and collaboration in the management of marine resources. Government instruments for resource management in California (e.g. Marine Life Management Act) and Baja California (e.g. State Fishery Inventory) recognize the potential contributions of population sources located in the territorial waters of the respective neighboring state. Joint research is needed to improve our understanding of these contributions and promote binational management. Differential fishing pressure for some species and the consequent status of the population is another factor that needs careful binational consideration. For example, populations of lucrative pink abalone (*Haliotis corrugata*) in the central region of the Baja California Peninsula show a high allelic diversity, a larger effective population size, and lack of a recent genetic bottleneck. This is contrary to what has been reported for the populations in California, which is consistent with the collapse of the fishery in 1990s (Munguía-

Vega et al. 2015).

Marine protected areas (MPAs) are spatial management tools used to protect and restore marine ecosystems (Lubchenco et al. 2003), with the aim to maintain or enhance the ecosystem services that the oceans provide. Traditionally, MPAs were established independently through community-based government effort (Gleason et al. 2010). However, recently there have been examples of regional-scale planning processes to design MPA networks, which are ecologically connected and managed as a larger system (Airame et al. 2003; Fernandes et al. 2005; Saarman et al. 2013; Botsford et al. 2014). The scheme, design, and implementation of MPAs are significantly different between the USA and Mexico. For example, the Marine Life Protection Act (MLPA) initiative successfully redesigned California's existing MPAs through a legal mandate, but in Baja California (BC) there is a lack of similar MPA networks or initiatives (Morgan et al. 2005; Arafeh-Dalmau 2016).

Between 2004 and 2011, with a scientific advisory team involving stakeholders directly in its design, the MLPA initiative public-private partnership planned MPAs networks in four separate regions of California's coast (Kirlin et al. 2013; Botsford et al. 2014). This effort resulted in 124 marine protected areas, including 9.4% of state waters placed in no-take marine reserves.

In Mexico, MPAs are indistinctly called Natural Protected Areas, and in the Pacific coast of Baja California there is a lack of decreed no-take MPAs. In December of 2016, the Mexican government declared all the islands on the Pacific coast of Baja California Peninsula as a biosphere reserve, extending the protection to the marine territory that surrounds the islands, including their kelp forest ecosystems (DOF 2016). This decree restricts some fishing activities around the islands, yet they can not be considered no-take MPAs. There is, however, one example of successful establishment of a MPA through community-based processes led by local fisherman. In 2006, 8% of the fishing grounds around Isla Natividad were voluntarily established by the fisherman as no-take areas (Micheli et al. 2012). Collaborative efforts between local fisherman and NGOs might be a starting point for a community-based process to design and establish MPAs in Baja California (Arafeh-Dalmau 2016).

## Human Impacts on Kelp Forests: What Do We Know?

Human activities have become ecological drivers of kelp forest communities, through pollution from storm water and wastewater, land use practices that affect coastal sedimentation, and disposal of dredged sediments (Dayton et al. 1998). The introduction of exotic species and serial overfishing of key predators and herbivores can affect non-targeted species via interactive cascades among interdependent species (e.g., Byrnes et al. 2006). All of these effects have been well documented and are known with relative certainty. It is clear that changes in ocean temperature and acidity may interact with one another and/or have differing impacts on these forests, further complicating the issue (Brown et al. 2014; Gaitán-Espitia et al. 2014).

One of the most studied processes in kelp forests is the dynamic relationship between kelp grazers and their predators, which can be greatly impacted by humans who harvest both (Mann 1982; Dayton 1985). Sea urchins are the most important kelp grazers, and their fecundity and grazing activity are so great that they can quickly overgraze entire kelp forests (Estes and Palmisano 1974; Ebeling et al. 1985). These areas, termed 'urchin barrens', are typically less productive and diverse than forested areas, and they can persist for decades (Graham 2004). Classical "top-down" control of kelp forests by sea otters (*Enhydra lutris*), voracious predators of sea urchins, has been suggested for central California kelp forests (Tinker et al. 2008; Carr and Reed 2016). Sea urchin outbreaks and overgrazing have been attributed to the removal of sea urchin predators such as large spiny lobsters and California sheephead (*Semicossyphus pulcher*) in southern California forests (Hamilton and Caselle 2015). There is also evidence that protecting areas from harvest in MPAs reduces sea urchin overgrazing, thereby enhancing production, diversity, and resilience to disturbances such as storms (Nichols et al. 2015).

Living in highly-variable nearshore environments, giant kelp has developed acclimation mechanisms to cope with temperature variability (Koch et al. 2016). However, extreme temperatures may play a role in determining latitudinal range limits in giant kelp, which has evolved to grow along a 30-degree latitudinal range in the Northeast Pacific Ocean spanning a temperature gradient from less than 2°C to over 20°C (Graham et al. 2007; Macaya and Zuccarello 2010). Warming could expand giant kelp forests at high latitudes, but polar distributions are also constrained by low light and herbivory (Gaines and Lubchenco 1982; Van den Hoek 1982; Jackson 1987). At low latitudes, giant kelp distributions are thought to be limited by warm temperatures, low nutrients, and competition with other species of macroalgae (Steneck et al. 2002; Schiel and Foster 2015).

Two recent events provide excellent case studies on the ecological effects of warming on giant kelp forests and provide hints at potential future scenarios. In central California, a thermal outfall from the Diablo Canyon nuclear power plant heated a small cove by an average of +3.5 °C for a decade (1985–1995). In a rigorous 18-year study carried out before and after warming, Schiel et al. (2004) found that elevated temperatures created ecological 'winners' that were mainly southern species that can colonize and compete for resources, and 'losers', that were northern affinity species which distribution may be contracted north or adapt to new conditions, algae and invertebrates among them, with 38% increasing, 49% decreasing, and 13% showing no change relative to control areas.

Another recent study found equally surprising results. From late 2013 to 2016, anomalously warm water in the northeastern Pacific Ocean (dubbed "the Blob") followed by very strong El Niño conditions caused rapid warming of coastal waters along the coast of California and Baja California (Cavole et al. 2016; Di Lorenzo & Mantua 2016). Despite anomalously high temperatures for 31 of 34 months (up to 5 °C above the 1982–2014 average) and low nutrients ($< 1$ μmol nitrate $L^{-1}$) for 19 of 34 months, the abundance and composition of giant kelp, understory macroalgae, sessile invertebrates, and reef fishes did not change substantially in this particular region of southern California (Reed et al. *in review*). Sea urchins and sea stars, however, declined dramatically due to diseases that can be magnified by warming (Reed et al. *in review*). The combined effects of the warm Blob and El Niño during 2015–2016 devastated giant kelp and red sea urchin populations in southern Baja California (G. Torres-Moye *personal observation*). Changes associated with the Blob event, but also reported for El Niño seasons, have included geographical shifts of species such as pelagic red crabs and tuna; the decline or closure of commercially important fisheries, including market squid and Dungeness crab; and the stranding of marine mammals and seabirds (Lea and Rosenblatt 2000; Chavez et al. 2002; Cavole et al. 2016).

In addition to more variable physical conditions and extreme events, the CCS is subject to a suite of chemical changes associated with climate change, including OA and hypoxia (Feely *et al.* 2008; Chan *et al.* 2008; Doney et al. 2009). In particular, severe hypoxic conditions have been observed off the coast of Oregon, USA, since 2002 and subsequently at other locations within the California Current (Chan *et al.* 2008; Micheli *et al.* 2012; Booth *et al.* 2014). Both et al. (2014) examine data of water quality monitoring program and found that dissolved oxygen (DO) had declined up to four times faster than offshore waters over the last 15 years, such low dissolved oxygen levels have no precedent over the past 50 years (Chan *et al.* 2008; Booth *et al.* 2014; Chu et al. 2015). Seasonal events of OA, are already appearing along the continental shelf of CCS, with the upwelling of corrosive seawater, approximately 40 years earlier than predicted by models (Feely et al. 2008; Doney et al. 2009). Concurrently, over the past 50 years, oceanographic measurements have revealed negative trends of DO concentrations in waters overlaying the Oxygen Minimum Zone (OMZ), naturally oxygen-depleted deep waters found between 600-1200 m depths (Stramma et al. 2008). The OMZ has shoaled by 90 m off southern California (Bograd *et al.* 2008), and circulation models predict that the oxygen content of the global ocean will decrease by 1-7% over the next century (Keeling *et al.* 2010). Documentation of climate-driven hypoxia on continental shelves and coastal areas (Chan et al. 2008; Booth et al. 2014) and the observed acidification trends (Feely et al. 2008; Doney et al. *2009*) suggest that hypoxia and acidification will have important influences on the structure, function and flow of services of coastal marine ecosystems.

## Unanswered Questions

Kelp forests provide a wide range of ecosystem services above and beyond those discussed previously, including nutrient cycling, biodiversity, wave attenuation, cultural heritage and the resilience of marine and coastal ecosystems. Although poorly evaluated to date, these services nevertheless are vital to human welfare. The biogenic structure that kelp creates may help prevent coastal damage caused by erosion, floods, and storm events (Smale et al. 2013). Giant kelp can reduce currents and dampen higher frequency internal waves (Rosman et al. 2007). The effect of attenuation is correlated with the extent, density, and morphology of canopy-forming kelps and understory macroalgae assemblages (Eckman et al., 1989; Gaylord et al. 2007; Rosman et al. 2007).

The species diversity in kelp forests, while supporting some of the aforementioned ecosystem services, may also enhance the productivity and ecological resilience of the ecosystem, increasing also its ability to implement internal mechanism that ameliorate the impact of a disturbance (Léveque 2003; Hughes and Stachowicz 2004). Numerically abundant species in kelp forest systems are unlikely to go extinct as a result of human pressures, but habitat fragmentation and population decline are expected to reduce the genetic diversity within populations (Hughes and Stachowicz 2004). How to estimate the economic value of biodiversity is not well understood. Diversity could affect a wide variety of services that humans receive from ecosystems, underscoring the need for resource management to consider the important role of maintaining biodiversity (Beaumont et al. 2008). Biodiversity is maintained by genetic, species and functional diversity within an ecosystem. The loss of the former can often result in the loss of the latter two. Biodiversity associated with kelp forests (Graham et al. 2007) may represent a reservoir of genetic diversity and resources for future use (Vasquez et al. 2013).

Atmospheric climate change may be altering nutrient delivery to giant kelp forests by changing the frequency and intensity of upwelling in the eastern North Pacific Ocean. When nutrient limitation causes widespread extinction, such as during very strong El Niño events, demographic connectivity with remnant populations (Castorani et al. 2015) or deep-water populations (Ladah and Zertuche-González 2004), or local survival of latent developmental stages (Carney et al. 2013), may be important for recovery. For shorter, seasonal episodes of limited upwelling, other sources of nitrogen may sustain giant kelp growth and persistence, including terrestrial runoff or ammonium excreted by reef animals or effluxed from sediment (Hepburn and Hurd 2005; Fram et al. 2008; Brzezinski et al. 2013). However, relatively little is known about the role of ammonium in supporting giant kelp through low-nitrate periods, nor whether ammonium dynamics will shift under climate change (Brzezinski et al. 2013; Schiel and Foster 2015).

Although nutrient availability can limit persistence, giant kelp has the potential to adapt to local conditions. In laboratory experiments and field transplantations, giant kelp from warm-water populations has greater survival and growth under warm, low-nutrient conditions than giant kelp from colder-water populations (North 1971; Kopczak et al. 1991). With climate-driven changes to nutrients and temperatures anticipated in the coming century, more work is needed to assess the scales and consequences of local adaptation in giant kelp (Johansson et al. 2015; Schiel and Foster 2015).

Since the 1950s, wave energy has increased globally, including in the eastern North Pacific Ocean (Bromirski et al. 2003; Gulev and Grigorieva 2004; Menéndez et al. 2008; Ruggiero et al. 2010; Seymour 2011; Young et al. 2011). Under most emissions scenarios, climate models predict increasing wave magnitudes in temperate regions, including western North America, due in part to increasing frequencies of large cyclones in the South Pacific and storm intensification in the North Pacific (Easterling et al. 2000; Wang and Swail 2006a, 2006b, Leslie et al. 2007; Meehl et al. 2007; Semedo et al. 2013). Ongoing and future intensification of waves may have important repercussions for the distributions and dynamics of giant kelp forests, potentially leading to persistent local extinctions of giant kelp and shifts in the benthic community towards understory algae that are more resistant to large swells (Dayton et al. 1992, 1999; Byrnes et al. 2011).

Unfortunately, there is limited and sometimes-conflicting information about the direct effects of OA on kelp forest organisms (e.g., Dillon 2014; Fernandez-Subiabre 2015). Most studies suggest that non-calcifying algal species, such as giant kelp, will experience few negative effects and may possibly benefit from OA, for example, by increasing photosynthesis (Harley et al. 2012, Koch et al. 2013, Schiel and Foster 2015). The potential for marine species to adapt to OA is not well known and community effects may vary. Harley et al. (2012) hypothesized that, in contrast to the negative direct and indirect effects of warming, giant kelp from the southern range limits may respond positively to direct and indirect OA effects. The combination of species-specific OA impacts has the potential to reshape kelp forest community structure, shifting competitive interactions between fleshy and turf algae species and/or increasing grazing activity of abundant herbivores that feed on kelp (Hepburn et al. 2011; Dillon 2014).

We can safely assume that population connectivity of animals associated with kelp forest in California and Baja California is mainly regulated by oceanographic processes. Nevertheless, a lack of accurate, quantitative descriptions of ocean circulation at different scales, as well as the increase on frequency and intensity of oceanographic variability generated by climate change, limit our understanding of connectivity processes. Few studies have examined the connectivity of kelp forest species across different spatial scales along their distributional range. The conservation and management of species that inhabit kelp forests will benefit from the combined knowledge of connectivity among populations across the California and Baja California border, and from understanding its seasonal and annual variability (DiBacco et al. 2006; Le Corre et al. 2012).

## Thinking Ahead: Priorities for Future Bi-national Research and Training Initiatives

Cooperative activities between the US and Mexican governments take place under a number of arrangements and treaties. There are, however, few examples of binational agreements regarding the management of marine resources, possibly because of a lack of appreciation of the advantages for each nation of binational efforts. Even though binational collaboration can be challenging due to language barriers, differential development of scientific structure and human resources, and disproportional funding, pursuing binational research, increasing cooperation, and building infrastructure undoubtedly generates shared benefits, such as better fisheries management, marine conservation strategies, and collaboration in scientific research and monitoring. An excellent example of the advantages and benefits of closer collaboration, especially in the research perspectives was provided by the Joint Working on Ocean Sciences between the Mexican National Sciences Academy (Academia Mexicana de Ciencias) and the US National Research Council (NRC), that produced a template for increased cooperation between ocean scientists and policymakers from Mexico and the United States, to the benefit of the citizens of both nations (AMC-NRC 1999). Mexican and US agencies should cooperate in establishing a coordinated observing system that improves marine monitoring efforts. Government agencies and foundations should fund coordinated marine research that addresses challenges from a transboundary perspective. The coordination between the two countries would improve if there were a continuous communication channel to address opportunities and challenges that are of binational interest. Capacity building is needed to move forward on all of these issues, and agencies should provide support for cross-border programs designed to provide training, field and laboratory experience to graduate students of both countries, as well as promote mechanisms for scholarly exchanges. The Mexican government should also investigate the need to establish a government entity responsible for marine affairs, including oceanic science and technology.

Monitoring change, anticipating possible ecological responses, and supporting social and ecological adaptation are key current and future priorities for maintaining the coastal ecosystems and economies along the California Current System. Bi-national coordination and new initiatives in support of coastal ecosystems and economies are most urgently needed in at least three areas: (1) coastal biophysical monitoring; (2) coordination of research on social-ecological coastal systems; and (3) capacity building, exchange of perspectives, and transfer of skills and technologies.

Coastal biophysical monitoring. Tracking physical variability and ecological responses requires continued monitoring, particularly in highly variable and heterogeneous ecosystems such as the upwelling ecosystems of the CCS. Several nearshore ecological monitoring programs exist in California and Baja California, particularly for kelp forest ecosystems, but most have been concentrated in specific locations, have never been integrated regionally, and face an uncertain future because of declining resources allocated to monitoring. Expanding, coordinating and integrating physical and ecological nearshore monitoring is critical in order to determine how regional climate and oceanographic events translate into physical variability along the coastline and across the CCS, the patterns and drivers of this variability, the influences on ecosystem function and flow of services; and the locations, species, and functions that are most vulnerable or resilient to climate change.

Social-ecological coastal systems. Understanding how ecosystems and human communities respond to, and are affected by, regional change requires that these two dimensions of coastal systems be investigated simultaneously. Social-ecological systems (SES) frameworks have been applied to investigating the resilience of coastal fisheries to climate variability and fishing intensity in central California (Aguilera et al. 2015), the role of exclusive access privileges and co-management in underlying the high performance of some fisheries in central Baja California (McCay et al. 2014), and trade-offs in achieving ecological and social sustainability across different regions of the Baja California Peninsula (e.g., Leslie et al. 2015). Bi-national, collaborative application of this framework, spanning the great ecological, social, and institutional diversity of the CCS, would produce crucial insights on the behaviors and feedbacks of coastal SES, and would provide critical information and networks for designing and implementing adaptive strategies.

Capacity building, exchanges, and technologies. A third critical need is to promote a greater flow and exchange of knowledge, competences, and technologies across the region, as well as between researchers and policy makers. The CCS contains a large number of academic institutions, NGOs, agencies, and voluntary citizen groups with enormous potential for tackling the grand challenges of the 21st century. However this potential is not fully realized because of the fragmentation, inefficiency, and isolation of research and education, caused mainly by political barriers. Expanding current mechanisms for facilitating exchange of skills and technologies, and for building capacity in the future generation of researchers, educators and decision-makers, is a key priority.

Citizens' involvement and participation are critical elements spanning these three future priorities. New programs need to involve fishers, divers, educators and a suite of other stakeholders in data collection and use. Evidence suggests that kelp forests in Baja California are contributing to the replenishment of California kelp forests, their biodiversity, genetic structure, and linked fisheries (Alheit & Bakun 2009; White et al. 2010). These southern kelp forests are likely to suffer the consequences of overfishing and climate change before California forests do because the southern limit kelp forests live at the edge of their physiological tolerance, where an increase in the mean sea temperature would likely jeopardize nutrient supply. In addition, Baja California kelp forests have not benefited from recent conservation and management actions in the US such as the Marine Life Protection Act's network of MPAs. This scarcity of conservation strategies and management actions stresses the importance of calling the attention of government agencies, not only addressing this opportunity, but even more, to tackle this issues from a bi-national perspective. Thus, to improve the adaptive capacity of this ecosystem and support effective management actions, we must look at the Baja California-California system as a whole. Bi-national collective action, through citizens' participation and the transparent generation and use of information, is our best hope in the face of a changing climate and escalating pressures on coastal ecosystems and human communities.

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# Endnotes

Allelic diversity.- the actual number of alleles present at a locus, the specific location or position of a gene's DNA sequence, on a chromosome.

Aragonite.- a mineral consisting of calcium carbonate, typically occurring in white seashells

Conspicuous fish.- fish species that are clearly visible and attract the attention for size and/or color.

Cryptic fish.- classification of fish species that for its size, color (camouflage) or behavior are difficult to notice.

Ecosystem engineer.- is any organism that creates, significantly modifies, maintains or destroys a habitat. These organisms can have a large impact on the species richness and landscape-level heterogeneity of an area.

Genetic bottleneck.- is a sharp reduction in the size of a population due to environmental events (such as earthquakes, floods, fires, disease, or droughts)

Hypoxia.- oxygen deficiency in a biotic environment.

Ocean acidification.- Ocean acidification is the decline in surface seawater pH caused by the sustained absorption of anthropogenically-derived atmospheric CO2 (Caldeira and Wickett 2003).

Oxygen Minimum Zone.- sometimes referred to as the shadow zone, is the zone in which oxygen saturation in seawater in the ocean is at its lowest. This zone occurs at depths of about 200 to 1,000 meters, depending on local circumstances.

Pelagic ecosystems.- marine organism that live in the water column of coastal and ocean but not on or near the bottom of the sea. They can be contrasted with demersal fish, which live on or near the bottom, and reef fish, which are associated with coral reefs.

Resilience.- was defined as the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures (defined as alternative stable states).

Sessile invertebrates.- Organisms that usually live on a substrate without the ability to move

Top-down control.- refers to when a top predator controls the structure or population dynamics of the ecosystem. The classic example is of kelp forest ecosystems. In such ecosystems, sea otters are a keystone predator. They prey on urchins which in turn eat kelp.

Upwelling.- is a process in which deep, cold water rises toward the surface.

## References

Aalbers, A., C. Sepulveda. 2015. Seasonal movement patterns and temperature profiles of adult white seabass (*Atractoscion nobilis*) off California. Fish. Bull. 113:1–14.

Aguilera, S.E., J. Cole, E.M. Finkbeiner, E. Le Cornu, N.C. Ban, M.H. Carr, J.E. Cinner, L.B. Crowder, S. Gelcich, C.C. Hicks, J.N. Kittinger, R. Martone, D. Malone, C. Pomeroy, R.M. Starr, S. Seram, R. Zuercher, K. Broad. 2015. Managing small-scale commercial fisheries for adaptive capacity: Insights from dynamic social-ecological drivers of change in Monterey Bay. PLoS One 10(3): e0118992. doi: 10.1371/journal/pone/0118992

Airame, S., J.E. Dugan, K.D. Lafferty, H. Leslie, D.A. McArdle, R.R. Warner. 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications 13 (1):170-184.

Alberto, F., P.T. Raimondi, D.C. Reed, J.R. Watson, D.A. Siegel, S. Mitarai, E.A. Serrao. 2011. Isolation by oceanographic distance explains genetic structure for *Macrocystis pyrifera* in the Santa Barbara Channel. Mol. Ecol., 20 (2011):2543–2554

Alheit, J., A. Bakun. 2010. Population synchronies within and between ocean basins: Apparent teleconnections and implications as to physical-biological linkage mechanisms. Journal of Marine Systems 79:267–285.

AMC-NRC (Academia Mexicana de Ciencias-US National Research Council). 1999. Building Ocean Science Partnerships: The United States and Mexico working together. National Academy Press. Washington, D.C., 292 p.

Andrews, H.L. 1945. The kelp beds of the Monterey region. Ecology, 26: 24-37.

Arafeh-Dalmau, N. 2016. Diseño de una red de Áreas Marinas Protegidas en un contexto transfronterizo: Enlazando Baja California con las Áreas Marinas Protegidas de California. MSc. thesis. Universidad Autónoma de Baja California. 45p.

Bakun, A., 1990. Global climate change and intensification of coastal ocean upwelling. Science 247, 198–201.

Beaumont, N.J., M.C. Austen, S.C. Mangi, M. Townsend. 2008. Economic valuation for the conservation of marine biodiversity. Marine Pollution Bulletin 56:386-396.

Bedford, D. 2001. Giant Kelp. In California's Living Marine Resources: A Status Report. W.S. Leet, C. M. Dewees, R. Klingbeil, E.J. Larson (eds.) California Department of Fish and Game. Sacramento, California. pp. 277-281.

Bell, T.B., K.C. Cavanaugh, D.C. Reed, D.A. Siegel. 2015. Geographic variability in the controls of biomass dynamics of giant kelp. Journal of Biogeography 42, 2010–2021.

Beltz, E. 2006 Scientific and Common Names of the Reptiles and Amphibians of North America – Explained. http://ebeltz.net/herps/etymain.html

Bernardi, G., L.T. Findley, A. Rocha-Olivares. 2003. Vicariance and dispersal across Baja California in disjunct marine fish populations. Evolution; International Journal of Organic Evolution. 57: 1599-609.

Bixler, H.J., H. Porse. 2011. A decade of change in the seaweed hydrocolloids industry. Journal of Applied Phycology 23: 321-335.

Bograd, S.J., C.G. Castro, E. Di Lorenzo, D.M. Palacios, H. Bailey, H., Gilly, W., Chavez, F.P., 2008. Oxygen declines and the shoaling of the hypoxic boundary in the California Current. Geophysical Research Letters 35. (art. L12607). doi:10.1029/2008GL034185.

Bograd, S.J., R.J. Lynn. 2003. Long-term variability in the southern California Current System. Deep Sea Research Part II: Topical Studies in Oceanography 50, 2355–2370.

Botsford L.W., J. Wilson White, M.H. Carr, J.E. Caselle. 2014. Marine Protected Area Networks in California, USA. Advances in Marine Biology, 69:205-251.

Booth, J.A.T., C.B. Woodson, M. Sutula, F. Micheli, S.B. Weisberg, S.J. Bograd, A. Steele, J. Schoen, L. B. Crowder. 2014. Patterns and potential drivers of declining oxygen content along the Southern California coast. Limnology and Oceanography 59(4):1–14.

Braje, T.J., J.M. Erlandson, T.C. Rick, P.K. Dayton, M. Hatch. 2009. Fishing from past to present: continuity and resilience of red abalone fisheries on the Channel Islands, California. Ecological Applications 19, 906–919.

Bromirski, P. D., R.E. Flick, D.R. Cayan. 2003. Storminess variability along the California coast: 1858–2000. Journal of Climate 16:982–993.

Brown, M.B., M.S. Edwards, K.Y. Kim. 2014. The effects of rising ocean temperature and $pCO_2$ on the physiology and growth of giant kelp, *Macrocystis pyrifera*, and grazing by purple urchins, *Strongylocentrotus purpuratus*. Algae. 29:203–15.

Brzezinski, M.A., D.C. Reed, S. Harrer, A. Rassweiler, J.M. Melack, B.M. Goodridge, J.E. Dugan. 2013. Multiple sources and forms of nitrogen sustain year-round kelp growth on the inner continental shelf of the Santa Barbara Channel. Oceanography 26:114–123.

Byrnes, J.E., D.C. Reed, B.J. Cardinale, K.C. Cavanaugh, S.J. Holbrook, R.J. Schmitt. 2011. Climate-driven increases in storm frequency simplify kelp forest food webs. Global Change Biology, 17(8): 2513-2524

Byrnes, J.E., J.J. Stachowicz, K.M. Hultgren, A. Randall Hughes, S.V. Olyarnik, C.S. Thornber. 2006. Predator diversity strengthens trophic cascades in kelp forests by modifying herbivore behavior. Ecology Letters 9, 61–71.

Cadien D.B., L.L. Lovell. 2015. A taxonomic listing of benthic macro- and megainvertebrates. Edition 10. The Southern California Association of Marine Invertebrate Taxonomists Natural History Museum of Los Angeles County Research & Collections. L.A. 167 pp.

Caldeira, K., M.E. Wickett. 2003. Oceanography: anthropogenic carbon and ocean pH. Nature 425:365–365.

Carney, L.T., A.J. Bohonak, M.S. Edwards, F. Alberto. 2013. Genetic and experimental evidence for a mixed-age, mixed-origin bank of kelp microscopic stages in southern California. Ecology 94: 1955–1965.

Carr, M.H. 1994. Effects of macroalgal dynamics on recruitment of a temperate reef fish. Ecology 75:1320– 1333.

Carr M.H., D.C. Reed. 2016. Shallow rocky reefs and kelp forest In: Ecosystems of California. Mooney H. and E. Zavaleta (eds.). University of California Press. 311-336 pp.

Casas-Valdez, M., E. Serviere-Zaragoza, D. Lluch-Belda, R. Marcos-Ramírez, N. Aguila Ramírez, N. 2003. Effects of climatic change on the harvest of the kelp *Macrocystis pyrifera* at the Mexican Pacific coast. Bulletin of Marine Science, Vol.73, No.3, (September 2003), pp. 445-456. ISSN 007-4977.

Castorani, M.C.N., D.C. Reed, F. Alberto, T.W. Bell, R.D. Simons, K.C. Cavanaugh, D.A. Siegel, P.T. Raimondi. 2015. Connectivity structures local populations dynamics: a long-term empirical test in a large metapopulation system. Ecology 96:3141-3152.

Cavanaugh, K.C., D.A. Siegel, P.T. Raimondi, F.A. Alberto. 2014. Patch definition in metapopulation analysis: a graph theory approach to solve the mega-patch problem. Ecology 95:316–328.

Cavole L.M., A.M. Demko, R.E. Diner, A. Giddings, I. Koester, C.M.L.S. Pagniello, M. Paulsen, A. Ramírez-Valdez, S. Schwenck, N. Yen, M.E. Zill, P. Franks. 2016. Biological Impacts of the 2013 – 2015 Warm-Water Anomaly in the Northeast Pacific: winners, losers and the future. Oceanography 29(2):273–285

CDFG (California Department of Fish and Game). 2009. California commercial and recreative landings for 2009. CDFG, Sacramento, CA.

Chan, F., J. Barth, J. Lubchenco, J. Kirincich, A. Weeks, H. Peterson, W.T. Mengl, B.A. Chan. 2008. Emergence of anoxia in the California Current Large Marine Ecosystem, Science, 319, p. 920.

Chavez, F.P., C.A. Collins, A. Huyer, D.L. Mackas. 2002. El Niño along the west coast of North America, Progress in Oceanography, 54(1-4), 1-5.

Chavez, F.P., J. Ryan, S.E. Lluch-Cota, M. Ñiquen. 2003. From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science 299, 217–221.

Checkley, D.M., J.A. Barth. 2009. Patterns and processes in the California Current System. Progress in Oceanography 83, 49–64.

Chu, J.W.F., V. Tunnicliffe. 2015. Oxygen limitations on marine animal distributions and the collapse of epibenthic community structure during shoaling hypoxia. Global Change Biology (2015)21:2989-3004.

Clough-Riquelme, J., N.L. Bringas. 2006. Equity and sustainable development: reflections from the U.S.-Mexico border. U.S.-Mexico contemporary perspectives series. Center for U.S.-Mexican Studies, UCSD. 362 pp.

Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. ONeill, J. Paruelo, R.G. Raskin, P. Sutton, M. vandenBelt. 1997. The value of the world's ecosystem services and natural capital. Nature. 387(6630):253-260

Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. ONeill, J. Paruelo, R.G. Raskin, P. Sutton, M. vandenBelt. 1998. The value of ecosystem services: putting the issues in perspective. Ecol. Econ. 25, 67–72

Cowen, R.K. 1985. Large scale pattern of recruitment by the labrid, *Semicossyphus pulcher*: causes and implications. Journal of Marine Research. 43(3):719-742.

Cowen, R. K., C.B. Paris, A. Srinivasan. 2006. Scaling of connectivity in marine populations. Science 311:5760, (Jan 27), pp. 522-527, 0036-8075

Crain, C. M., K. Kroeker, B.S. Halpern. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11:1304–1315.

Cramer, J. 1998. Population growth and air quality in California. Demography. 1998;35(1):45–56.

Daugherty, A.E. 1997. Marine Mammals of California. Department of Fish and Game. Electronic format rendered May 1997.

Dawson E.Y., M. Neushul, R.D. Wildman. 1960. Seaweeds associated with kelp beds along southern California and Northwestern Mexico. Pacific Naturalist 1: 25–81.

Dayton, P.K., M.J. Tegner. 1984. Catastrophic storms, El Niño, and patch stability in a southern California kelp community. Science 224:283–285.

Dayton P.K., V. Currie, T. Gerodette, B.D. Keller, R. Rosenthal, D.A. Ven Tresca. 1984. Patch dynamics and stability of some California kelp communities. Ecological Monographs, 54(3): 253-289.

Dayton, P.K., M.J. Tegner, P.B. Edwards, K.L. Riser. 1998. Sliding baselines, ghosts, and reduced expectations in kelp forest communities. Ecological Applications 8:309–322.

Dayton, P.K., M.J. Tegner, P.B. Edwards, K.L. Riser. 1999. Temporal and spatial scales of kelp demography: the role of oceanography climate. Ecological Monographs 69:219–250.

Dayton, P.K., M.J. Tegner, P.E. Parnell, P.B. Edwards. 1992. Temporal and spatial patterns of disturbance and recovery in a kelp forest community. Ecological Monographs 62:421–445.

Dayton, P.K., 1985. Ecology of kelp communities. Annual review of ecology and systematics 215–245.

Di Lorenzo, E. and N. J. Mantua. 2016. The Northeast Pacific heatwave of 2014/15. Nature Climate Change. 1-11. doi:10.1038/nclimate3082

Di Lorenzo, E., A.J. Miller, N. Schneider, J.C. McWilliams. 2005. The warming of the California Current System: dynamics and ecosystem implications. Journal of Physical Oceanography 35:336–362.

Di Lorenzo, E., V. Combes, J.E. Keister, P.T. Strub, A.C. Thomas, P.J.S. Franks, M.D. Ohman, J.C. Furtado, A. Bracco, S.J. Bograd, W.T. Peterson, F.B. Schwing, S. Chiba, B. Taguchi, S. Hormazabal, C. Parada. 2013. Synthesis of Pacific Ocean climate and ecosystem dynamics. Oceanography 26:68–81.

Di Lorenzo, E., N. Schneider, K.M. Cobb, P.J.S. Franks, K. Chhak, A.J. Miller, J.C. McWilliams, S.J. Bograd, H. Arango, E. Curchitser, T.M. Powell, P. Rivière. 2008. North Pacific Gyre Oscillation links ocean climate and ecosystem change. Geophysical Research Letters 35:1–6.

Díaz-Viloria, N., P. Cruz, S.A. Guzmán-del Próo, R. Perez-Enriquez. 2009. Journal of Shellfish Research 3: 599-608.

DiBacco, C., L.A. Levin, E. Sala. 2006. Connectivity in marine ecosystems: the importance of larval and spore dispersal. In: Crooks KR, Sanjayan M. (eds) Connectivity conservation. Conservation biology, Vol 14. Cambridge University Cambridge, p 184–213.

Dillon, E. 2014. Effects of pH on the growth, herbivory and chemical defenses of *Macrocystis pyrifera* apical meristems. Honors thesis. Stanford, USA. 30pp.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas. 2009. Ocean acidification: the other $CO_2$ problem. Annual Review of Marine Science 1:169–192.

Dutton, A., A.E. Carlson, A.J. Long, G.A. Milne, P.U. Clark, R. DeConto, B.P. Horton, S. Rahmstorf, M.E. Raymo. 2015. Sea-level rise due to polar ice-sheet mass loss during past warm periods. Science 349, aaa4019.

Easterling, D.R., G.A. Meehl, C. Parmesan, S.A. Changnon, T.R. Karl, L.O. Mearns. 2000. Climate extremes: observations, modeling, and impacts. Science 289:2068–2074.

Ebeling, A.W., D.R. Laur, R.J. Rowley. 1985. Severe storm disturbances and reversal of community structure in a southern California kelp forest. Marine Biology, 287-294.

Eckman, J.E., D.O. Duggins, A.T. Sewell. 1989. Ecology of understory kelp enviroments. 1. Effects of kelp on flow and particle transport near the bottom. Journal of Experimental Marine Biology and Ecology 129: 173-187.

Edwards, M.S. 2004. Estimating scale-dependency in disturbance impacts: El Niños and giant kelp forests in the northeast Pacific. Oecologia 138:436– 447.

Edwards, M.S., J.A. Estes. 2006. Catastrophe, recovery and range limitation in NE Pacific kelp forests: a large-scale perspective. Marine Ecology Progress Series 320:79–87.

Edwards, M.S., G. Hernández-Carmona. 2005. Delayed recovery of giant kelp near its southern range limit in the North Pacific following El Niño. Marine Biology 147:273–279.

Erisman, B.E., L.G. Allen, D.J. II Pondella, J. Claisse, E. Miller, J. Murray. 2011. Illusions of Plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Canadian Journal of Fisheries and Aquatic Sciences 68:1705-1716.

Estes, J.A., J.F. Palmisano. 1974. Sea otters: their role in structuring nearshore communities. Science 185: 1058-1060.

Feely, R.A., C.L. Sabine, J.M. Hernandez-Ayon, D. Ianson, B. Hales. 2008. Evidence for upwelling of corrosive “acidified” water onto the continental shelf. Science 320:1490–1492.

Fernandes L., J.C. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De’ath, B. Mapstone, H.

Marsh, H.P. Possingham, I. Ball, T. Ward, K. Dobbs, J. Aumend, D. Slater, K. Stapleton. 2005. Establishing representative no-take areas in the Great Barrier reef: large-scale implementation of theory on marine protected areas Conservation Biology, 19 (2005), pp. 1733–1744

Fernandez-Subiabre, P.A. 2015. The effects of ocean acidification on photosynthesis, growth and carbon and nitrogen metabolism of *Macrocystis pyrifera*. Ph.D. thesis. University of Otago, NZ. 262 pp.

Fontana-Uribe, S. 2005. Filogeografía de *Pisaster ochraceus* Brandt, 1835 (Echinodermata: Asteroidea) a lo largo de su distribución. Master Thesis. CICESE. 106 p.

Foster, M.S., D.R. Schiel. 1985. The ecology of giant kelp forests in California: A community profile. Biological Report 85 (7.2). Washington, D.C.: U.S. Fish and Wildlife Service.

Foster, M.S., D.C. Reed, M.H. Carr, P.K. Dayton, D.P. Malone, J.S. Pearse, L. Rogers-Bennett. 2013. Kelp forest in California. Smithsonian Contributions to the Marine Sciences. 115-132.

Fram, J.P., H.L. Stewart, M.A. Brzezinski, B. Gaylord, D.C. Reed, S.L. Williams, S. MacIntyre. 2008. Physical pathways and utilization of nitrate supply to the giant kelp, *Macrocystis pyrifera*. Limnology and Oceanography:1589–1603.

Freiwald, J. 2012. Movement of adult temperate reef fishes off the west coast of North America. Canadian Journal of Fisheries and Aquatic Sciences. 69(8): 1362-1374.

Funes-Rodríguez, R., J.A. Ruíz-Chavarría, R. González-Armas, R. Durazo, S.A. Guzmán-del Proó. 2015. Influence of Hydrographic Conditions on the Distribution of Spiny Lobster Larvae off the West Coast of Baja California, Transactions of the American Fisheries Society, 144(6) 11-22.

Gaines, S.D., J. Lubchenco. 1982. A unified approach to marine plant-herbivore interactions. II. Biogeography. Annual Review of Ecology and Systematics 13:111–138.

Gaitán-Espitia, J.D., J.R. Hancock, J.L. Padilla-Gamiño, E.B. Rivest, C. Blanchette, D.C. Reed, G.E. Hofmann. 2014. Interactive effects of elevated temperature and $pCO_2$ on early life-history stages of the giant kelp *Macrocystis pyrifera*. Journal of Experimental Marne Biology and Ecology. 457:51–8.

Garden, C.J., A.M. Smith. 2015. Voyages of seaweeds: The role of macroalgae in sediment transport, Sediment. Geol. 318(2015) 1–9.

Gaylord, B., J.H. Rosman, D.C. Reed, J.R. Koseff, J. Fram, S. MacIntyre, K. Arkema, C. McDonald, M.A. Brzezinski, J.L. Largier. 2007. Spatial patterns of flow and their modification within and around a giant kelp forest. Limnology and Oceanography:1838–1852.

GEBC (Gobierno del Estado de Baja California). 2015a. Comunicado 1470 de la Dirección de Comunicación Social. Mexicali, Baja California. México.

GEBC (Gobierno del Estado de Baja California). 2015b. Programa Estatal de Turismo de Baja California 2015-2019. Mexicali, Baja California. México.

Gleason, M.G., S. McCreary, M. Miller-Henson, J. Ugoretz, E. Fox, M. Merrifield, W. McClintock, P. Serpa, K. Hoffmann. 2010. Science-based and stakeholder driven marine protected area network planning: a successful case study from north-central California. Ocean & Coastal Management 53, 52-68.

Graham, M.H. 2004. Effects of local deforestation on the diversity and structure of southern California giant kelp forest food webs. *Ecosystems*, *7*(4), 341-357.

Graham, M.H., J.A. Vásquez, A.H. Buschmann. 2007. Global ecology of the giant kelp Macrocystis: from ecotypes to ecosystems. Oceanography and Marine Biology 45:39–88.

Graham, N.E., Diaz, H.F., 2001. Evidence for intensification of North Pacific winter cyclones since 1948. Bulletin of the American Meteorological Society 82, 1869.

Greene, C., K. Andrews, T. Beechie, D. Bottom, R. Brodeur, L. Crozier, A. Fullerton, L. Johnson, E. Hazen, N. Mantua, C. Menza, M. Sheer, W. Wakefield, C. Whitmire, M. Yoklavich, J. Zwolinski. 2013. Selecting and evaluating indicators for habitats within the California Current large marine ecosystem. In: Harvey, C.J., N. Garfield, E.L. Hazen, G.D. Williams (eds.). The California Current Integrated Ecosystem Assessment: Phase III Report. Available from http://www.noaa.gov/iea/Assets/iea/california/Report/pdf/9.Habitat_2013.pdf

Gulev, S.K., V. Grigorieva. 2004. Last century changes in ocean wind wave height from global visual wave data. Geophysical Research Letters 31:L24302.

Guzmán-del Próo, S.A., S. De la Campa-Guzmán, J.L. Granados-Gallegos. 1971. El sargazo gigante (*Macrocystis pyrifera*) y su explotación en Baja California. Revista de la Sociedad Mexicana de Historia Natural XXXII(12):15-49.

Hallam, A., P.B. Wignall. 1999. Mass extinctions and sea-level changes. Earth-Sciences Reviews 48, 217–250.

Hamilton S.L., J.E. Caselle. 2015. Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forests. Proceedings of the Royal Society of London B: Biological Sciences. 282: 20141817.

Harley, C.D., K.M. Anderson, K.W. Demes, J.P. Jorve, R.L. Kordas, T.A. Coyle, M.H. Graham. 2012. Effects of climate change on global seaweed communities. Journal of Phycology 48, 1064–1078.

Hepburn, C.D., C.L. Hurd. 2005. Conditional mutualism between the giant kelp *Macrocystis pyrifera* and colonial epifauna. Marine Ecology Progress Series 302:37–48.

Hepburn, C.D., D.W. Pritchard, C.E. Cornwall, R.J. McLeod, J. Beardall, J.A. Raven, C. L. Hurd. 2011. Diversity of carbon use strategies in a kelp forest community: implications for a high $CO_2$ ocean. Global Change Biology 17:2488–2497.

Hernández-Carmona G., B. Hughes, M. Graham. 2006. Reproductive longevity of drifting kelp *Macrocystis pyrifera* (Phaeophyceae) in Monterey Bay. Journal of Phycology 42 (6):1199-1207.

Hernández-Carmona G., D. Robledo, E. Serviere-Zaragoza. 2001. Effect of nutrient availability on *Macrocystis pyrifera* recruitment survival near its southern limit of Baja California. Botanica Marina 44: 221-229.

Hernández-Carmona. G., Y.E. Rodríguez, J.R. Torres, I. Sánchez, M.A. Vilchis, O. García. 1989. Evaluación de mantos de *Macrocystis pyrifera* (Phaeophyta: Laminariales) en Baja California, México. I. Invierno 1985 - 1986. Ciencias Marinas 15: 1-27.

Holbrook, S.J., R.J. Schmitt, J.S. Stephens Jr. 1997. Changes in an assemblage of temperate reef fishes associated with a climate shift. Ecological Applications 7, 1299–1310.

Horn, M.H., L.G. Allen, R.N. Lea. 2006. Biogeography. In: The ecology of marine fishes. California and adjacent waters, L.G. Allen, D.J. Pondella, M.H. Horn (eds.) Berkeley: University of California Press. pp. 3–25.

Hubbard, K. 2008. Status of the Fisheries Report. California Department of Fish and Game. 6p.

Hughes, A.R., J.J. Stachowicz. 2004 Genetic diversity enhances the resistance of a seagrass ecosystem to disturbance. Proc. Natl Acad. Sci. USA 101, 8998 – 9002.

Huyer, A., 1983. Coastal upwelling in the California Current system. Progress in Oceanography 12, 259–284.

Iacchei, M., T. Ben-Horin, K.A. Selkoe, C.E. Bird, F.J. García-Rodríguez, R.J. Toonen. 2013. Combined analyses of kinship and FST suggest potential drivers of chaotic genetic patchiness in high gene-flow populations. Molecular Ecology, 22: 3476–3494. doi: 10.1111/mec.12341

IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jackson, G.A. 1983. The physical and chemical environment of a kelp community. In: Bascom, W. (ed.) The effects of waste disposal on kelp communities. Southern California Coastal Water Research Project, Long Beach, p. 11-37

Jackson, G.A. 1977. Nutrients and production of giant kelp, *Macrocystis pyrifera*, off southern California. Limnology and Oceanography 22:979–995.

Jackson, G.A. 1987. Modelling the growth and harvest yield of the giant kelp *Macrocystis pyrifera*. Marine Biology 95:611–624.

Johansson, M.L., F. Alberto, D.C. Reed, P.T. Raimondi, N.C. Coelho, M.A. Young, P.T. Drake, C. A. Edwards, K. Cavanaugh, J. Assis, L. B. Ladah, T. W. Bell, J. A. Coyer, D. A. Siegel, and E. A. Serrão. 2015. Seascape drivers of *Macrocystis pyrifera* population genetic structure in the northeast Pacific. Molecular Ecology 24:4866–4885.

Johnson, C.R., S.C. Banks, N.S. Barrett, F. Cazassus, P.K. Dunstan, G.J. Edgar, S.D. Frusher, C. Gardner, M. Haddon, F. Helidoniotis, K.L. Hill, N. J. Holbrook, G. W. Hosie, P.R. Last, S.D. Ling, J. Melbourne-Thomas, K. Miller, G.T. Pecl, A.J. Richardson, K.R. Ridgway, S.R. Rintoul, D.A. Ritz, D. J. Ross, J. C. Sanderson, S.A. Shepherd, A. Slotwinski, K.M. Swadling, N. Taw. 2011. Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. Journal of Experimental Marine Biology and Ecology 400:17–32.

Jones C.G., Lawton J.H., Shachak M. 1994. Organisms as ecosystem engineers. Oikos 69:373-386.

Keeling, R.F., A. Körtzinger, N. Gruber. 2010. Ocean Deoxygenation in a Warming World. Annual Review in Marine Science 2: 199–229.

Kenner, M. C., J.A. Estes, M. T. Tinker, J.L. Bodkin, R.K. Cowen, C. Harrold, B.B. Hatfield, M. Novak, A. Rassweiler, D.C. Reed. 2013. A multi-decade time series of kelp forest community structure at San Nicolas Island, California. Ecology, 94(11): 26-54.

Kildow, J., C. S. Colgan. 2005. California's Ocean Economy, Report to the Resources Agency, State of California, Prepared by the National Ocean Economics Program.

Kinlan, B.P., M.H. Graham, J.M. Erlandson. 2005 Late-Quaternary changes in the size and shape of the California Channel Islands: implications for marine subsidies to terrestrial communities. Proc. Calif. Isl. Symp. 6, 119–130.

Kinlan, B., S. Gaines. 2003. Propagule Dispersal in Marine and Terrestrial Environments: A Community Perspective. *Ecology, 84*(8), 2007-2020.

Kirlin, J., M. Caldwell, M. Gleason, M. Weber, J. Ugoretz, E. Fox, M. Miller-Henson. 2013. California's Marine Life Protection Act Initiative: supporting implementation of legislation establishing a statewide network of marine protected areas. Ocean & Coastal Management 74, 3-13.

Koch, K., M. Thiel, W. Hagen, M. Graeve, I. Gomez, D. Jofre, L. C. Hofmann, F. Tala, K. Bischof. 2016. Short- and long-term acclimation patterns of the giant kelp *Macrocystis pyrifera* (Laminariales, Phaeophyceae) along a depth gradient. Journal of Phycology 52:260–273.

Koch, M., G. Bowes, C. Ross, X.H. Zhang. 2013. Climate change and ocean acidification effects on seagrasses and marine macroalgae. Global Change Biology 19:103–132.

Kopczak, C.D., R.C. Zimmerman, J.N. Kremer. 1991. Variation in nitrogen physiology and growth among geographically isolated populations of the giant kelp, *Macrocystis pyrifera* (Phaeophyta). Journal of Phycology 27:149–158.

Koslow, A.J., R. Goericke, W. Watson. 2013. Fish assemblages in the southern California Current: relationships with climate, 1951–2008. Fisheries Oceanography 22, 207–219.

Kushner, D. J., A. Rassweiler, J. McLaughlin, K. Lafferty. 2013. A multi-decade time series of kelp forest community structure at the California Channel Islands. Ecology, 94: 26-55.

Ladah, L.B., J.A. Zertuche-González. 2004. Giant kelp (*Macrocystis pyrifera*) survival in deep water (25–40 m) during El Niño of 1997–1998 in Baja California, Mexico. Botanica Marina 4: 367–372.

Ladah, L.B., J.A. Zertuche-González, G. Hernández-Carmona. 1999. Giant kelp (*Macrocystis pyrifera*, Phaeophyceae) recruitment near its southern limit in Baja California after mass disappearance during ENSO 1997–1998. Journal of Phycology 35, 1106–1112.

Léveque, C. 2003. Ecology from ecosystem to biosphere. Science Pub Inc, Enfield NH, USA. pp. 472.

Le Corre N., F. Guichard, L.E. Johnson. 2012. Connectivity as a management tool for coastal ecosystems in changing oceans (Ch 11), in: Marcelli M. (ed.). Oceanography (INTECH) 236-258.

Lea, R.N., R.H. Rosenblatt. 2000. Observations on fishes associated with the 1997–98 El Niño off California. CalCOFI Report 41:117–129.

Leachman, J.C. 1921. Indian uses of kelp. Scientific American Monthly 212:137–140.

Leeworthy, V.R., P.C Wiley. 2001. "Current Participation Patterns in Marine Recreation" National Survey On Recreation and The Environment 2000. US Department of Commerce. National Oceanic and Atmospheric Administration. National Ocean Service. Special Projects. Silver Spring, Maryland

Leslie, L.M., D.J. Karoly, M. Leplastrier, B.W. Buckley. 2007. Variability of tropical cyclones over the southwest Pacific Ocean using a high-resolution climate model. Meteorology and Atmospheric Physics 97:171–180.

Leslie H.M., X. Basurto, M. Nenadovic, L. Sievanen, K.C. Cavanaugh, J.J. Cota-Nieto, B.E. Erisman, E. Finkbeiner, G. Hinojosa-Arango, M. Moreno-Báez, S. Nagavarapu, S.M.W. Reddy, A. Sánchez-Rodríguez, K. Siegel, J.J. Ulibarria-Valenzuela, A. Hudson-Weaver, O. Aburto-Oropeza. 2015. Operationalizing the social-ecological systems framework to assess sustainability. Proceedings of the National Academy of Sciences, 112 (19) 5979-5984.

Ling S.D., Johnson C.R., Frusher S.D., Ridgway K.R. 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci 106(52):22341–22345

Love, M.S., M. Yoklavich, L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley, California.

Lowe, W.H., F.W. Allendorf. 2010. What can genetics tell us about population connectivity? Molecular Ecology, 19, 3038–3051

Lubchenco J., S. Andelman, S. Gaines, S.R. Palumbi. 2003. Plugging a hole in the ocean: an introduction to the special issue on marine reserves. Ecological Applications 13: S3–7.

Macaya, E.C., G.C. Zuccarello. 2010. DNA barcoding and genetic divergence in the giant kelp *Macrocystis* (Laminariales). Journal of Phycology 46:736–742.

Mann, K.H. 1982. Kelp, sea urchins and predators: a review of strong interactions in rocky subtidal systems of eastern Canada, 1970–1980. Netherlands Journal of Sea Research 16, 414–423.

McCay, B.J., F. Micheli, G. Ponce-Díaz, G. Murray, G. Shester, S. Ramirez-Sanchez, W. Weisman. 2014. "Cooperatives, concessions, and co-management on the Pacific Coast of Mexico." Marine Policy 44: 49-59.

McGowan, J.A., S.J. Bograd, R.J. Lynn, A.J. Miller. 2003. The biological response to the 1977 regime shift in the California Current. Deep Sea Research Part II: Topical Studies in Oceanography 50, 2567–2582.

Mead, G.R. 1976. The ethnobotany of the California Indians, a compendium of the plants, their uses. University of Northern Colorado, Greeley, Colorado.

Meehl, G. A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver, Z.-C. Zhao. 2007. Global climate projections. Pages 748–845 in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller (eds.) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Menéndez, M., F.J. Méndez, I.J. Losada, N.E. Graham. 2008. Variability of extreme wave heights in the northeast Pacific Ocean based on buoy measurements. Geophysical Research Letters 35:L22607.

Methot, R., T. Jagielo, S. Heppell. 2004. Panel report: California sheephead stock assessment. California Department of Fish and Game, Sacramento, CA. Available at: www.dfg.ca.gov/marine/sheephead2004/pdfs/report.pdf

Micheli, F., A. Saenz-Arroyo, A. Greenley, L. Vazquez, J.A. Espinoza Montes, M. Rossetto, G.A. De Leo. 2012. Evidence That Marine Reserves Enhance Resilience to Climatic Impacts. PLoS ONE 7(7):1-8.

Miller, E.F. 2014. Status and Trends in the Southern California Spiny Lobster Fishery and Population: 1980–2011, Bulletin, Southern California Academy of Sciences, 2014: 113-114

Miller, A.J., D.R. Cayan, T.P. Barnett, N.E. Graham, J.M. Oberhuber. 1994. The 1976–77 climate shift of the Pacific Ocean. Oceanography 7, 21–26.

Morgan, L., S. Maxwell, F. Tsao, T.A.C. Wilkinson, P. Etnoyer. 2005. Marine Priority Conservation Areas: Baja California to the Bering Sea. Commission for Environmental Cooperation of North America and the Marine Conservation Biology Institute. Montreal, February 2005.

Mumme, S.P. 1999. Managing Acute Water Scarcity on the U.S.- Mexico Border: Institutional Issues Raised by the. Natural Resources Journal 39(1): 149.

Munguía-Vega A., A. Sáenz-Arroyo, A.P. Greenley, J.A. Espinoza-Montes, S.R. Palumbi, M. Rossetto, F. Micheli. 2015. Marine reserves help preserve genetic diversity after impacts derived from climate variability: Lessons from the pink abalone in Baja California. Global Ecology and Conservation, 4: 264-276

Murray, S.N., M.M. Littler. 1981. Biogeographical analysis of intertidal macrophyte floras of southern California. Journal of Biogeography 8: 339-351.

Nam, S., H.-J. Kim, U. Send. 2011. Amplification of hypoxic and acidic events by La Niña conditions on the continental shelf off California. Geophysical Research Letters 38.

Neushul, P. 1987. Energy from marine biomass: The historical record. Pages 1–37 in K. T. Bird, P.H. Benson (eds.) Seaweed Cultivation for Renewable Resources. Elsevier Science Publishers B. V., Amsterdam.

Nichols, K.D., L. Segui, K.A. Hovel. 2015. Effects of predators on sea urchin density and habitat use in a southern California kelp forest. Marine Biology 162, 1227–1237.

NOAA (National Oceanic and Atmosphere Administration). 2008. Fisheries of the United States 2006. National Marine Fisheries Service Office of Science and Technology. Maryland, USA.

North, W.J. 1971. The biology of giant kelp beds (*Macrocystis*) in California: introduction and background. Nova Hedwigia 32:1–68.

Parnell, P.E., P.K. Dayton, R.A. Fisher, C.C. Loarie, R.D. Darrow. 2010a. Spatial patterns of fishing effort off San Diego: Implications for zonal management and ecosystem function. Ecological Applications 20: 2203–2222.

Parnell, P.E., E.F. Miller, C.E. Lennert-Cody, P.K. Dayton, M.L. Carter, T.D. Stebbins. 2010b. The response of giant kelp (*Macrocystis pyrifera*) in southern California to low-frequency climate forcing. Limnology and Oceanography 55:2686–2702.

Paterson, C.N., C.L. Chabot, J.M. Robertson, J.J. Cota-Nieto, B. Erisman, L.G. Allen. 2015. The Genetic Diversity and Population Structure of Barred Sand Bass, Paralabrax nebulifer: A Historically Important Fisheries Species off Southern and Baja California. Calcofi Reports 56: 97-109.

Pendleton, L.H., J. Rooke. 2006. Understanding the Potential Economic Value of SCUBA Diving and Snorkeling. http://linwoodp.bol.ucla.edu/

Rassweiler, A., K.K. Arkema, D.C. Reed, R.C. Zimmerman, M.A. Brzezinski. 2008. Net primary production, growth, and standing crop of *Macrocystis pyrifera* in southern California. Ecology 89: 2068.

Reed D.C., M.A. Brzezinski. 2009. Kelp forest. In: Laffoley, D.d'A., G. Grimsditch. (eds). 2009. The management of natural coastal carbon sinks. IUCN, Gland, Switzerland. 53 pp.

Reed, D.C., B.P. Kinlan, P.T. Raimondi, L. Washburn, B. Gaylord, P.T. Drake. 2006. A metapopulation perspective on the patch dynamics of giant kelp in southern California. Pages 353–386 *in* J. P. Kritzer and P. F. Sale, editors. Marine Metapopulations. Academic Press, San Diego, California, USA.

Reed, D.C., A. Rassweiler, K.K. Arkema. 2008. Biomass rather than growth rate determines variation in net primary production by giant kelp. Ecology 89: 2493–2505.

Reed, D.C., A. Rassweiler, K.K. Arkema. 2009. Density derived estimates of standing crop and net primary production in the giant kelp *Macrocystis pyrifera*. Marine Biology 156: 2077–2083.

Reed, D.C., A. Rassweiler, M.H. Carr, K.C. Cavanaugh, D.P. Malone, D.A. Siegel. 2011. Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. Ecology, 92: 2108-2116

Reed, D.C., L. Washburn, A. Rassweiler, R.J. Miller, T.W. Bell. In review. Extreme warming challenges kelp forests as sentinels of climate change. Nature Communications.

Ridgway, K., K. Hill. 2012. East Australian Current. A Marine Climate Change Impacts and Adaptation Report for Australia.

Robledo, D. 1998. Seaweed resources of Mexico. In: Critchley, A.T., M. Ohno (eds.) Seaweed resources of the world, pp. 331–342. Tokyo, Japanese International Cooperation Agency.

Romo-Curiel, A.E., S.Z. Herzka, C.A. Sepulveda, P. Pérez-Brunius, S.A. Aalbers. 2016. Rearing conditions and habitat use of white seabass (*Atractoscion nobilis*) in the northeastern Pacific based on otolith isotopic composition, Estuarine, Coastal and Shelf Science, 170(5): 134-144.

Rosman, J.H., J.R. Koseff, S.G. Monismith, J. Grover. 2007. A field investigation into the effects of a kelp forest (*Macrocystis pyrifera*) on coastal hydrodynamics and transport, Journal of Geophysics Research 112, C02016, doi:10.1029/2005JC003430.

Rubin-Kurtzman, J.R., R. Ham-Chande, M.D. Van Arsdol. 1996. "Population in Trans-Border Regions: The Southern California-Baja California Urban System." The International Migration Review 30, (4): 1020-045.

Ruggiero, P., P.D. Komar, J.C. Allan. 2010. Increasing wave heights and extreme value projections: the wave climate of the US Pacific Northwest. Coastal Engineering 57:539–552.

Rykaczewski, R.R., J.P. Dunne. 2010. Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model. Geophysical Research Letters 37:1–5.

Saarman, E., M. Gleason, J. Ugoretz, S. Airame, M.H. Carr, A. Frimodig, T. Mason, J. Vasques, E. Fox. 2013. The role of science in supporting marine protected area network planning and design in California. Ocean & Coastal Management 74, 45-56.

Schiel, D.R., M.S. Foster. 2015. The Biology and Ecology of Giant Kelp Forests. University of California Press, Berkeley, California, USA. 416 p.

Schiel, D.R., J.R. Steinbeck, M.S. Foster. 2004. Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. Ecology 85:1833–1839.

Schimmelmann, A., C.B. Lange. 1996. Tales of 1001 varves: a review of Santa Barbara Basin sediment studies. Geological Society, London, Special Publications 116, 121–141.

SECTURE (Secretaría de Tusrismo del Estado de Baja California). 2000 Importancia económica del turismo para Baja California. SECTURE: México.

Selkoe, K.A., A. Vogel, S.D. Gaines. 2007. Effects of ephemeral circulation on recruitment and connectivity of nearshore fish populations spanning Southern and Baja California. Marine Ecology Progress Series 351:209–220. doi: 10.3354/meps07157

Semedo, A., R. Weisse, A. Behrens, A. Sterl, L. Bengtsson, H. Günther. 2013. Projection of global wave climate change toward the end of the twenty-first century. Journal of Climate 26:8269–8288.

SEPESCA (Secretaría de Pesca y Acuacultura del Estado de Baja California). 2015. Resumen annual de la producción pesqueria y acuícola en Baja California. Ensenada, Baja California.

Setchell, W.A., N.L. Gardner. 1925. The marine algae of the Pacific coast of North America. Univ. of California Press, Berkley. pp. 898

Seymour, R.J. 2011. Evidence for changes to the Northeast Pacific wave climate. Journal of Coastal Research 27:194–201.

Seymour, R.J., M.J. Tegner, P.K. Dayton, P.E. Parnell. 1989. Storm wave induced mortality of giant kelp, *Macrocystis pyrifera*, in southern California. Estuarine, Coastal Shelf Science. 28, 277–292.

Shaw, M.R., L. Pendleton, D.R. Cameron, B. Morris, D. Bachelet, K. Klausmeyer, J. MacKenzie, D.R. Conklin, G.N. Bratman, J.H. Lenihan, E. Haunreiter, C. Daly, P.R. Roehrdanz. 2011. The impact of climate change on California's ecosystem services. Climatic Change 109 (Suppl 1 ), 5465-5484.

Schroeder, D.M., M.S. Love. 2002. Recreational fishing and marine fish populations in California. CalCOFI Reports 43, 182–190.

Simmonds, S.E., B.P. Kinlan, C. White, G.L. Paradis, R.R. Warner, D.C. Zacherl. 2014. Geospatial statistics strengthen the ability of natural geochemical tags to estimate range-wide population connectivity in marine species. Marine Ecology Progress Series 508:33-51.

Smale, D.A., M.T. Burrows, P.J. Moore, N. O'Connor, S.J. Hawkins. 2013. Threats and knowledge gaps for ecosystem services provided by kelp forests: a northeast Atlantic perspective. Ecology and Evolution 3:4016–4038.

Sosa-Nishizaki, O., C. Guerrero-Ávila, E. García-Rodríguez, M.C. Rodríguez-Medrano, L.E. Saldaña-Ruíz, B.E. Mejía-Mercado, R.H. Domínguez-Reza, F. Castro-Velasco. 2013. Caracterización de la pesca deportiva en Baja California. Informe Técnico. Centro de Investigación Científica y Educación Superior de Ensenada (CICESE), 56 pp.

Spalding, M.D., H.E. Fox, G.R. Allen, N. Davidson, Z.A. Ferdaña, M. Finlayson, B.S. Halpern, M.A. Jorge, A. Lombana, S.A. Lourie, K.D. Martin, E. McManus, J. Molnar, C.A. Recchia, J. Robertson. 2007. Marine Ecoregions of the World: a bioregionalization of coast and shelf areas. BioScience 57: 573-583.

Steneck, R.S., M.H. Graham, B.J. Bourque, D. Corbett, J.M. Erlandson, J.A. Estes, M.J. Tegner. 2002. Kelp forest ecosystems: Biodiversity, stability, resilience, and future. Environmental Conservation 29:436–459.

Stewart, H. L., J.P. Fram, D.C. Reed, S.L. Williams, M.A. Brzezinski, S. MacIntyre, B.P. Gaylord. 2009. Differences in growth, morphology, tissue carbon, and nitrogen of *Macrocystis pyrifera* within and at the outer edge of a giant kelp forest in California, USA. Marine Ecology Progress Series 375:101–112.

Stocker, T.F., 2014. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Stramma, L., G.C. Johnson, J. Sprintall, V. Mohrholz. 2008. Expanding oxygen minimum zones in the tropical oceans. Science 320: 655–658.

Sugihara G., R. May, H. Ye, C. Hsieh, E. Deyle, M. Fogarty, S. Munch. 2012. Detecting causality in complex ecosystems. Science 338(6106): 496–500

Tegner, M.J., P.K. Dayton. 1987. El Niño effects on southern California kelp forest communities. Advances in Ecological Research 17:243– 279.

Tegner, M.J., P.K. Dayton. 2000. Ecosystem effects of fishing in kelp forest communities. ICES Journal of Marine Science, 57: 579-589.

Tinker, M.T., G.B. Bentall, J.A. Estes. 2008. Food limitation leads to behavioral diversification and dietary specialization in sea otters. Proceedings of the National Academy of Sciences 105(2):560-565.

Torres-Moye, G. 2012. Mainland and island kelp forest in northern Baja California, México: subtidal community structure, dynamics, and connectivity for the design of marine protected areas. PhD. Dissertation. University of California, Davis. 104 p.

Torres-Moye, G., M.S. Edwards, C.G. Montaño-Moctezuma. 2013. Benthic community structure in kelp forests from the Southern California Bight. Ciencias Marinas, 39(3): 239-252.

Van den Hoek, C. 1982. The distribution of benthic marine algae in relation to the temperature regulation of their life histories. Biological Journal of the Linnaean Society 18:81–144.

Vásquez, J.A., S. Zuñiga, F. Tala, N. Piget, D.C. Rodríguez D.C., J.M. Alonso-Vega. 2014. Economic valuation of kelp forests in northern Chile: values of goods and services of the ecosystem. Applied Phycology (2014) 26: 1081. doi:10.1007/s10811-013-0173-6

Vojkovich M., R.J. Reed. 1983. White seabass, *Atractoscion nobilis*, in California Mexican waters: status of the fishery. CalCOFI Reports 24: 79–83.

Wang, X.L.L., V.R. Swail. 2006a. Climate change signal and uncertainty in projections of ocean wave heights. Climate Dynamics 26:109–126.

Wang, X.L.L., V.R. Swail. 2006b. Historical and possible future changes of wave heights in northern hemisphere oceans. Page 240 in W. Pierre, editor. Atmosphere-Ocean Interactions: Vol. 2 (Advances in Fluid Mechanics Series Vol. 39). Wessex Institute of Technology Press, Southampton, U.K.

Warner R.R., S.E. Swearer, J.E. Caselle, M. Sheehy, G. Paradis. 2005. Natal trace-elemental signatures in the otoliths of an open-coast fish. Limnol. Oceanogr. 50(5): 1529-1542.

White, C., K.A. Selkoe, J. Watson, D.A. Siegel, D.C. Zacherl, R.J. Toonen. 2010. Ocean currents help explain population genetic structure. Proceedings of the Royal Society Biological Sciences 277:1685-1694. doi: 10.1098/rspb.2009.2214

Wilmers, C.C., J.A. Estes, M. Edwards, K.L. Laidre, B. Konar, 2012. Do trophic cascades affect the storage and flux of atmospheric carbon? An analysis for sea otters and kelp forests. Frontiers in Ecology and Environment 10, 409–415 (2012).

Young, I.R., S. Zieger, and A.V. Babanin. 2011. Global trends in wind speed and wave height. Science 332:451–455.

Zacherl, D.C. 2005. Spatial and temporal variation in statolith and protoconch trace elements as natural tags to track larval dispersal. Marine Ecology-Progress Series 290:145-163.

Zacherl, D., S.D. Gaines, S.I. Lonhart. 2003. The limits to biogeographical distributions: insights from the northward range extension of the marine snail, *Kelletia kelletii* (Forbes, 1852). Journal of Biogeography 30:913-924.

# CONCLUSIONS

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This work has analyzed a selection of marine resource management and conservation case studies from across the United States (U.S.)-Mexico political border. The analysis included the evaluation of asymmetry in scientific knowledge, resource management strategies, and ecosystem services. This final section presents the main conclusions of the analysis of fish distribution in the biogeographic transition between the warm-temperate and subtropical systems, the analysis of asymmetry in the management of the giant sea bass and kelp forest, and the review of the existing knowledge of the kelp forests throughout California (U.S.) and Baja California (Mexico) and how climate change will likely impact them.

The first chapter reviewed the distribution of fish species to the south of the U.S.-Mexico border region. This analysis show that the Cedros archipelago fish community is a species-rich assemblage, with a fairly even blend of temperate and tropic-subtropical affinity species. The marked break between the San Diegan and the Cortez biogeographic provinces includes five continental islands and is located in the east-central region of the Baja California Peninsula. To the north of the Cedros archipelago, temperate species associated with rocky reefs and kelp forests begin to be dominant until Point Conception, California. To the south of the Cedros archipelago, species associated with the tropical Cortez and Mexican provinces begin to appear, mainly associated with mangrove ecosystems in estuaries and bays located in Bahia Magdalena. Species of affinity to cold-temperate waters and tropical-subtropical species are proportionally represented in this region.

In addition, 38% of the registered species have their distribution limit within this small geographic region. Of the nineteen species that presented new occurrences in the Cedros archipelago, ten were extensions south of previous distribution limits, two which were San Diego. The limited sampling effort south of the U.S.-Mexico border may be the most likely reason for the ranges in distribution. This work represents the first exhaustive fish checklist in the northern region of the Baja California Peninsula, different from that of Guadalupe Island. This study has shown the need for better scientific knowledge of this taxonomic group in the region and how this lack of knowledge can contribute to inadequate perceptions in the distribution of species.

The asymmetry in the management of shared resources between nations generates complex scenarios that hinder optimal use, creates disadvantages for one or both actors, and stifles conservation efforts. Two such scenarios on the U.S.-Mexico border are addressed with two case studies; (a) the critically endangered giant sea bass (*Stereolepis gigas*), and (b) the economic value of commercial fisheries in the kelp forest ecosystem. The conclusions of these case studies are presented below:

The conclusions of the critically endangered giant sea bass have been revealed as marked asymmetry in the scientific knowledge and management of the species across the U.S.-Mexico border, creating a complex scenario for fishery management and hampering conservation efforts. California introduced a ban in 1982 after the collapse of giant sea bass stocks due to overfishing, yet it is still an open fishery in Mexico today. This has led to a difference in the regulation of the fishery of the species, implications for the different managements of the fisheries, and knowledge of the species and its populations. The work in these chapters have collectively found that extremely strong asymmetry exists in scientific knowledge, economic input, and conservation methods across the U.S.-Mexico border, political regulations have both hidden and created illusions of false historical population collapses, and the total population size of giant sea bass is likely higher than previously estimated.

The analyses of the historical landings of the giant sea bass reveal that the collapse of its populations occurred much earlier than previously thought and that landings decline from the U.S. fleet in Mexican waters may be the result of regulation of the commercial fisheries between the U.S. and Mexico. The fishery landings analysis highlights three major findings: (a) high annual variability in catches, (b) location of main fishing grounds in southern Baja California, and (c) the population size of this species is likely higher than previously thought. The analysis from biological monitoring in the Mexican fleet leads to estimations that the giant sea bass population size could be larger than we previously thought. The catches from the U.S. and Mexican waters combined, totaling more than 53 tons per year, could represent up to 2,120 giant sea bass individuals per year. Considering that up to 48.4% of the giant sea bass landed by the Mexican commercial fishery are juvenile individuals, the adult individuals removed annually could be up to 1,026. A possible future scenario could see both countries with an equal proportion of the giant sea bass population. However, sustainable stocks in this scenario will not be likely without setting the foundations for binational management. It is in the best interests of both parties to recover the population of the giant sea bass from the perspective of fishing, its ecological role, and its cultural value.

In the kelp forests ecosystem case study, when considering only the extractive services of the commercial fishery, which represents a small fraction of all the benefits we obtain from this ecosystem, the results show the value provided may be upwards of US$9 million per year. Kelp forests are iconic ecosystems providing a wide range of services including direct use examples such as commercial and recreational fisheries, which represent an important economic and social component. The economic value estimates of the giant kelp forests ecosystem across the entire geographic distribution in the Northeastern Pacific are based on the most representative goods and services that this ecosystem provides to humans. Considering just the abalone fishery in Mexico, the economic value of production can be up to US$8 million in a fishing season. Unlike services that other ecosystems provide to humans, the loss of the giant kelp forest would also represent the total loss of some of these fisheries as they are highly dependent on the existence of giant kelp. The greater fishing production in Mexico of benthic species (i.e., spiny lobster, sea urchin) is the result of the combination of greater fishing landings and fishery management areas specifically directed to the habitat of these resources. This study successfully shows that the economic value of kelp forests ecosystem is significantly higher than previously thought considering fisheries alone. The results indicated the value reaching US$8.5 million per year when considering only five fisheries.

The coastal forests formed by the giant kelp *Macrocystis pyrifera* are primary habitats. In California and Baja California, they support high levels of species diversity and productivity in the region, acting as a refuge, nursery, and food provider for many species. The kelp forests and the populations of species that inhabit this ecosystem across the U.S.-Mexico border are connected through migration, dispersal, and genetic connectivity. Despite forming the same large marine ecosystem, the forests of California and Baja California have two very different histories.

California's kelp forests have a long history of fishing pressure, pressure from recreational activities, continuous long-term monitoring programs, and a network of marine protected areas. While the fishing pressure on the kelp forest in Baja California is more recent, few research monitoring initiatives exist, and a lack of spatial protection schemes is notable. There are more than 40 times more peer-reviewed papers on kelp forest ecosystem topics in California than in Baja California, furthering the asymmetric knowledge and management in the region. The lack of studies taking a binational approach is glaring when out of a total of 236 articles in the review, only nine peer-reviewed papers include sites on both sides of the border. As a result, the best strategy in the long run is transboundary cooperation through sharing cross-border marine resources and acknowledging the actions taken by one of the invariable parties affects the other.

In addition to its ecological importance, giant kelp forests and the ecosystem services they provide to humans are worth millions of dollars to the U.S. and Mexican economies, which may be lost or decreased due to climatic and non-climatic change stressors. Coastal human populations rely on many ecosystem services that kelp forest provide such as food and natural products, chemical products, recreational and commercial fisheries, ecotourism opportunities, cultural value, and nutrient cycling. The physical environment that supports kelp forests includes hard bottoms in waters shallow enough for light-limited germination and growth, exposure to cool nutrient-rich waters, surge, and low risks of sedimentation and turbidity. Human activities have become ecological drivers of kelp forest communities and the impacts of pollution, land use practices, disposal of dredged sediment, introduction of exotic species and overfishing of key predators and herbivores have been well documented and are relatively known. Although the same level of certainty is not available for the consequences, it is clear that changes in ocean temperature and acidity may interact with one another and have different impacts on these forests and that the kelp forests in the California and Baja California region are currently under stress due to overfishing, overgrazing, heat waves, and climate change. The literature review showed that the giant kelp and the biological communities it supports will likely react to climatic and non-climatic changes in complex ways, likely by contracting their southern extent due to warming waters, reductions in nutrient availability, increasing wave disturbance, and grazing by warm-water herbivores.