

Spatial structure of commercial marine fisheries in Northwest Mexico

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The spatial structure of commercial marine fisheries in Northwest (NW) Mexico was investigated using official landings data from 39 local fisheries offices in the region. Multivariate analyses revealed a clear spatial pattern in fishing activities, in which there was a positive linear relationship between the species composition of fisheries offices and both latitude and longitude. Fisheries offices formed eight distinct clusters organized by similarities in geographic location, species-group composition, and coastal habitat type. Five of the eight clusters comprised offices from the same geographic region and coastal ecosystem, and the other three clusters contained the largest industrial fishing ports in NW Mexico. The results of this study suggest that NW Mexico would benefit from an ecosystem-based management framework that focuses on the direct, spatial connection that exists between coastal habitats, harvested species groups, and fishing activities within each region. Subdivision into five separate regions is proposed, with management attention paid specially to the few industrialized ports whose fishing capacities and geographic ranges of fishing far exceed the other areas.

Keywords: ecosystem-based management, Gulf of California, marine fisheries, Northwest Mexico.

Introduction

Northwest (NW) Mexico, which ranges from Tijuana south to Nayarit and includes the Gulf of California and the Pacific coast of the Baja California peninsula, is 1 of 62 major marine provinces of the world, is recognized as a biodiversity hotspot for tropical reef conservation, and accounts for 50–70% of the annual fisheries production in Mexico (Roberts *et al.*, 2002; OECD, 2006; Spalding *et al.*, 2007). The rapid growth of commercial, recreational, and artisanal fisheries in the region over the past few decades has resulted in the overexploitation of most large fisheries, the collapse of high-trophic-level fisheries, and the widespread degradation of marine ecosystems and marine foodwebs (DOF, 2004a, b; Sala *et al.*, 2004; Velarde *et al.*, 2004). The recovery of the ecosystems and the creation of sustainable fisheries in NW Mexico are impeded by problems with intergovernmental coordination, conflict among sectors, limited institutional capacity, lack of enforcement and compliance, policies based on single species and stocks, poor social-management frameworks, and the large geographic scale of management (Salas *et al.*, 2007; Ezcurra *et al.*, 2009; Cinti *et al.*, 2010).

Scientists, regional non-governmental organizations, and the Mexican federal government have responded to these problems by promoting efforts that utilize ecosystem-based management (EBM) approaches to define conservation and fishery-management priorities for the region. Briefly, marine EBM incorporates the interactions within and among ecosystem components and multiple human activities, at different spatial

and temporal scales, into management decisions that seek to protect the structure, function, and key processes of marine ecosystems, while sustaining the services they provide to mankind (FAO, 2005; UNEP, 2006; Leslie and McLeod, 2007). Several studies have characterized critical habitats, complex ecosystems, and ecological processes and defined distinct ecoregions within NW Mexico, creating a spatial template for EBM in the region (Sala *et al.*, 2002; Carvajal *et al.*, 2004; Enriquez-Andrade *et al.*, 2005; Ulloa *et al.*, 2006; Spalding *et al.*, 2007; Lara-Lara *et al.*, 2008). Others have investigated interactions among and within social, ecological, and economic systems of fisheries in NW Mexico at different spatial and temporal scales (Leslie *et al.*, 2009; Cinti *et al.*, 2010; Cisneros-Mata, 2010; Moreno-Báez *et al.*, 2010). EBM has been initiated at the scale of local communities in relation to the management of small-scale fisheries and marine reserves (Cudney-Bueno *et al.*, 2009; Ezcurra *et al.*, 2009). Finally, a new fisheries law was passed in Mexico to establish and define principles for promoting and regulating the management and sustainable use of fisheries by taking into account social, technological, biological, and environmental aspects (OECD, 2006). That law seeks to improve the administration of fisheries resources through a focus on management plans for single species or species groups, e.g. sea basses and groupers, and regional management plans for certain coastal and marine areas. Although both are necessary components of EBM, the scale at which species- and regional-level management plans will be implemented and will interact has yet to be determined.

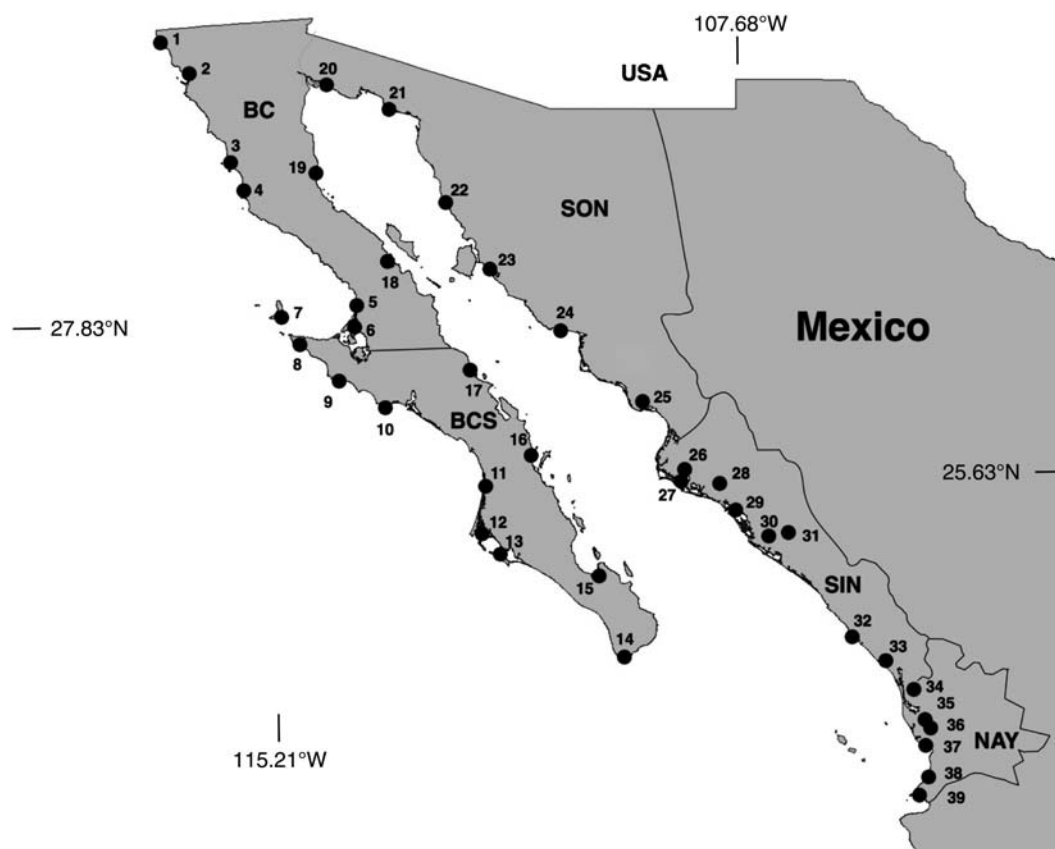


Figure 1. Map of NW Mexico showing the locations of the 39 LFOs used in the study. The names of the offices are listed in Table 1. BC, Baja California; BCS, Baja California Sur; NAY, Nayarit; SIN, Sinaloa; SON, Sonora.

Understanding how the spatial scale of fishing activities coincides with the geographic ranges of coastal habitats and harvested species is another critical step in successfully implementing EBM into the marine fisheries of NW Mexico. Such information will help to assess the impacts of fisheries on ecosystem structure and function, determine the proper spatial scale and the necessary level of interregional cooperation for management, and evaluate how different conservation and management policies may affect fishing economies (Wilson, 2006; Leslie and McLeod, 2007; Leslie *et al.*, 2009). To this end, the current spatial structure of commercial marine fisheries within NW Mexico was investigated using official landings data from the local fisheries offices (LFOs) of the Mexican National Commission of Fisheries and Aquaculture (CONAPESCA).

Material and methods

There are 47 LFOs of CONAPESCA located within NW Mexico, collectively registering the landings of commercial capture fisheries from five states: Baja California, Baja California Sur, Sonora, Sinaloa, and Nayarit. They are located at major ports and important fishing communities, and provide the most detailed fisheries data available. A database that included monthly landings for 207 species groups of fish and invertebrates from all 47 LFOs was obtained from CONAPESCA headquarters in Mazatlán, Sinaloa, Mexico. Species groups were classified in the database by regional common name, which varied considerably in taxonomic specificity from a single species, e.g. huachinango (Pacific

red snapper, *Lutjanus peru*) to a suite of species from the same genus, family, or class, e.g. burros (grunts), Haemulidae. Landings data from 39 LFOs and 123 species from 2001 to 2005 were used in the analyses (Figure 1). Data on monthly landings before 2001 were not available consistently over years or from LFOs, so were excluded. Eight LFOs were removed, because they registered landings only from inland freshwater bodies, or the landings of marine species were negligible. Freshwater and aquaculture species ($n = 84$) were also removed from the final dataset.

Spatial analyses

Several types of multivariate analysis were used to examine the spatial patterns of marine fisheries within NW Mexico. First, a correspondence analysis (CANOCO v. 4.5 software; Ter Braak and Smilauer, 2002) was performed to assess the level of variability in landings volumes and catch compositions among the 39 LFOs and to identify any spatial structure in those data. A detrended correspondence analysis was run to select the appropriate multivariate analyses for that dataset. The effect of data transformation on the maximum length of the gradient (MLG) was tested using raw data, log-transformed ($\log_{10} C + 1$), and square-root transformations. Raw data were used for the final correspondence analysis, because the MLG was greater than three units (Ter Braak and Smilauer, 2002). Rare species were downweighted to improve the final ordination, which focused on the scaling of interspecies group distances (similarities) to show a more quantitative representation of the correspondence between species groups and

LFOs in multivariate space. Species groups were arranged in multivariate space according to variations in their abundance among LFOs, in which distances between LFOs were used to indicate the degree of similarities in catch composition and landings. The Pearson rank correlation was used to test for a relationship between the final ordination scores of the LFOs with latitude or longitude.

Although a correspondence analysis can identify the existence of spatial structure in the data, it cannot define specific groups of LFOs *per se*. Therefore, a non-hierarchical cluster analysis (*k*-means analysis; Statistica v. 4.5) was performed using the same dataset to identify distinct clusters of LFOs. For this analysis, clusters are formed using an iterative process in which differences among groups at each step are maximized. This procedure was used to build collections of LFOs with the greatest similarity based on catch compositions, landings volumes, and within-cluster least variance.

Three procedures were performed to evaluate the performance of the *k*-means analysis. First, a pooled within-clusters, sum-of-squares distance (WK) was calculated to measure the quality of the partition of the data (Tibshirani *et al.*, 2005). It uses the Euclidean distances within clusters to evaluate the quality of the partition of a known number of clusters. Second, a Krzanowski and Lai (KL) index was calculated to determine the optimum number of clusters to be used in the *k*-means analysis (Krzanowski and Lai, 1988). Finally, similarities among the clusters of LFOs, or fisheries regions, were plotted using a multidimensional scaling (MDS) analysis to verify that clusters identified from the other analyses were meaningful.

Results

The fisheries of NW Mexico revealed a well-defined spatial structure with respect to the species composition of landings among LFOs, with the first and the second canonical axes of the correspondence analysis explaining 13.2 and 11.7% of the variability in landings volumes and catch compositions, respectively (Figure 2). The Euclidean distances among clusters were consistent with the actual geographic distances between regions. The arrangement of LFOs in multivariate space was transverse to axis 2, following a latitudinal pattern from temperate (positive values) to tropical waters (negative values) and a longitudinal (inverted) pattern from the Pacific coast of the Baja California peninsula (negative values) to coastlines of the Gulf of California (positive values) (Figure 3). Specifically, the LFO scores along axis 2 showed a positive relationship with latitude (linear correlation, $n = 39$, $r = 0.33$, $p = 0.04$) and a negative relationship with longitude (linear correlation, $n = 39$, $r = -0.61$, $p < 0.01$).

Results of the *k*-means analysis supported the results of the correspondence analysis and identified eight distinct clusters of LFOs (Table 1). The use of eight clusters in the *k*-means analysis produced the highest quality partition of the data (WK = 3.73) and the second highest value for the KL index (1.4), whereas both seven and nine clusters showed a lower quality of partition (3.46 and 3.13, respectively) and KL index (0.2 and 0.6, respectively). The MDS plot of the eight-cluster similarity also revealed a pattern consistent with geographic location (Figure 4). The clusters were arranged in a discrete pattern and did not overlap, indicating that the final ordination and the number of clusters were meaningful.

The number of LFOs within each cluster ranged from one to ten, and most regions included only LFOs from the same

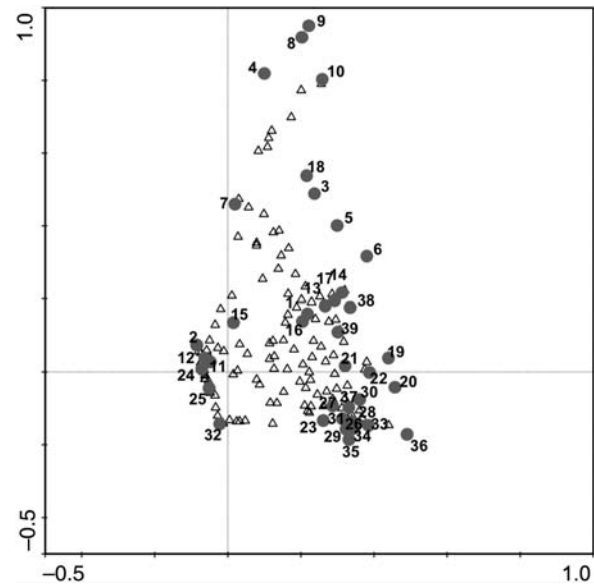


Figure 2. Correspondence analysis of landings volumes and species composition from LFOs in NW Mexico. Triangles represent species groups ($n = 123$), and dots with numbers represent fisheries offices ($n = 39$). The names of the fisheries offices are listed in Table 1.

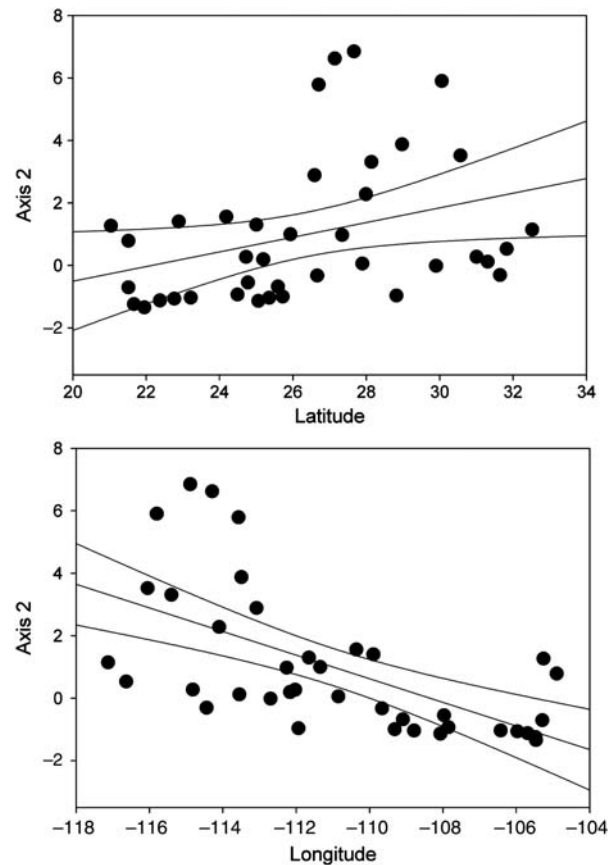
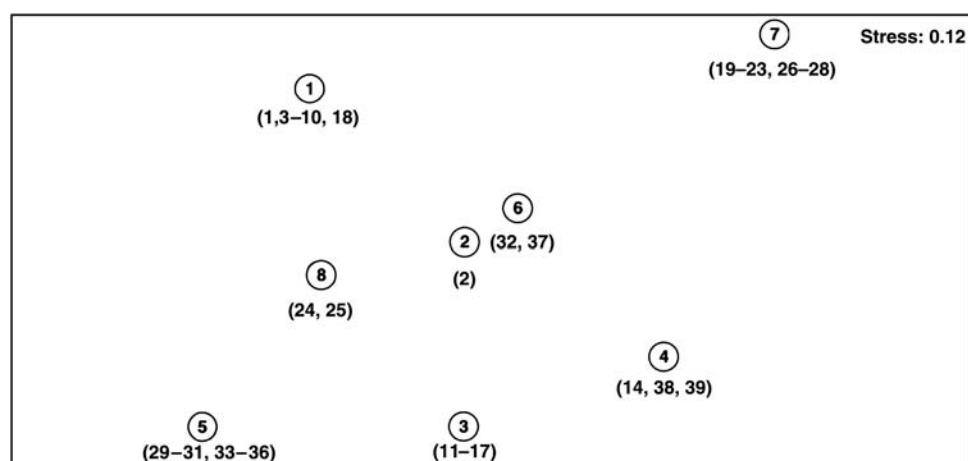


Figure 3. Linear correlation of the second canonical axis of the correspondence analysis of 39 LFOs in NW Mexico with latitude (top) and longitude (bottom). Lines reflect the 95% confidence intervals.

Table 1. Eight clusters of LFOs in NW Mexico, showing the numbers and names of each office, mean annual catch, and mean annual number of the targeted species groups.

LFO	Catch (t)	Species (#)	LFO	Catch (t)	Species (#)
Cluster 1			Cluster 2		
1. Tijuana-Rosarito, BC	165	36	2. Ensenada, BC	53 849	61
3. San Quintín, BC	982	48			
4. El Rosario, BC	1 227	43			
5. Jesús María, BC	565	44			
6. Guerrero Negro, BCS	907	55			
7. Isla Cedros, BCS	1 596	28			
8. Bahía Asunción, BCS	923	30			
9. Bahía Tortugas, BCS	1 361	46			
10. Punta Abreojos, BCS	938	43			
18. Bahía de los Ángeles, BC	567	49			
Cluster 3			Cluster 4		
11. Adolfo L. Mateos, BCS	7 437	67	14. Cabo San Lucas, BCS	172	24
12. San Carlos, BCS	32 578	75	38. Peñita de Jaltemba, NAY	326	31
13. Puerto Cortés, BCS	1 683	66	39. Cruz de Huanacastle, NAY	579	40
15. La Paz, BCS	1 969	65			
16. Loreto, BCS	538	47			
17. Santa Rosalía, BCS	14 101	70			
Cluster 5			Cluster 6		
29. La Reforma, SIN	1 823	30	32. Mazatlán, SIN	90 805	73
30. Navolato, SIN	1 972	41	37. San Blas, NAY	3 844	60
31. Culiacán, SIN	1 092	33			
33. Escuinapa, SIN	1 453	34			
34. Tecuala, NAY	1 167	34			
35. Tuxpan, NAY	2 386	19			
36. Santiago Ixcuintla, NAY	648	38			
Cluster 7			Cluster 8		
19. San Felipe, BC	2 538	36	24. Guaymas, SON	134 892	65
20. Golfo de Santa Clara, SON	1 869	23	25. Huatabampo, SON	40 302	57
21. Puerto Peñasco, SON	4 920	48			
22. Puerto Libertad, SON	1 088	33			
23. Bahía Kino, SON	7 344	49			
26. Los Mochis, SIN	3 017	43			
27. Topolobampo, SIN	2 090	51			
28. Guasave, SIN	3 985	42			

BC, Baja California; BCS, Baja California Sur; NAY, Nayarit; SIN, Sinaloa; SON, Sonora.

**Figure 4.** MDS plot of eight clusters of LFOs identified by similarities in relative landings volumes and species composition. The numbers inside the circles indicate a cluster, and the numbers in parenthesis indicate LFOs that correspond to that cluster. Clusters 1, 3, 4, 5, and 7 correspond to the five proposed fishing regions. Clusters 2, 6, and 8 are the largest industrial fishing ports in Mexico; they do not follow a regional pattern in fishing.

geographic region. However, Bahía de los Ángeles clustered with LFOs from the north Pacific coast of Baja California, and Cabo San Lucas clustered with LFOs from Nayarit owing to significant overlaps in species-group composition. Also, three clusters (cluster 2: Ensenada; cluster 6: Mazatlán, San Blás; cluster 8: Guaymas, Huatabampo) were formed as a result of the high landings volumes recorded for a large number of species groups, which separated them from all other clusters of LFOs. Notably, those three clusters were much closer to each other in multivariate space than to the other five clusters.

Discussion

A direct connection exists between the spatial structure of commercial marine fisheries and the marine ecosystems of NW Mexico. Based on the landings data of harvested species groups, LFOs can be divided into distinct clusters characterized by similarities in traits related to geographic location and species composition. Moreover, the geographic range that defines five of the eight identified clusters of fisheries offices complements the geographic distribution of the primary coastal habitats of NW Mexico described in earlier conservation exercises. For example, the geographic distribution of mangroves, wetlands, rocky reefs, and soft seabed habitats recorded by Carvajal *et al.* (2004) and the ecoregions designated by Ulloa *et al.* (2006) and Lara-Lara *et al.* (2008) are similar in scale and location to fisheries regions 1, 3, 4, 5, and 7. This implies that the ecological setting influences harvesting patterns, or more specifically that fishers target the coastal habitats with which they are most familiar, generally those in proximity to where they live. Although the spatial depletion of harvested species has expanded significantly, most fishers still operate within a range smaller than the spatial scale established with our analyses, particularly because of the vessels and technologies used by most artisanal fisheries in the region (McGoodwin, 1979; Sala *et al.*, 2004). Therefore, each of our identified fishery regions is essentially defined by the community structure of marine organisms that inhabit the coastal ecosystems of that region.

Seven of the 39 total LFOs did not cluster with LFOs of the same geographic region, and five of these LFOs formed three distinct clusters (cluster 2: Ensenada; cluster 6: Mazatlán, San Blás; cluster 8: Guaymas, Huatabampo) that were relatively close to each other but far from other clusters in multivariate space. This pattern probably emerged because commercial fishing enterprises based in those cities are more industrialized and operate at a much larger geographic and production scale than those in other fishing ports of NW Mexico. As a consequence, the highest landings volumes and the greatest number of targeted species groups are recorded in those five offices (Table 1). For example, large commercial fishing vessels, e.g. purse-seiners, trawlers, from Ensenada and Guaymas operate throughout the entire Gulf of California and beyond. Similarly, fishing enterprises from Guaymas set up seasonal fishing camps on many islands in the Gulf, and larger vessels make routine trips to each camp to collect and transport fish back to distribution plants several hundred kilometres away. The two other LFOs that did not cluster according to the geographic region were Bahía de los Ángeles and Cabo San Lucas. The LFO from Bahía de los Ángeles, which is located in the northern Gulf of California side of Baja California, clustered with LFOs from those of the Pacific coast of the Baja peninsula, because local fisheries target species groups present in both regions (Horn and Allen, 1978; Dawson

et al., 2006). Similarly, Cabo San Lucas clustered with the two LFOs from Nayarit, because commercial fisheries in both regions target a suite of tropical species groups that are not common to the north (Hastings *et al.*, 2010).

NW Mexico is currently managed as a single fisheries region by the Mexican government (OECD, 2006). The existence of the distinct fisheries regions identified here and the heterogeneity among them with respect to both ecological and socio-economic factors suggest that the spatial scale of management of NW Mexico is incompatible with the true scale under which commercial fisheries currently operate (see also Cisneros-Mata, 2010). We propose therefore that marine fisheries in NW Mexico be subdivided for management purposes into five geographically distinct regions comprising the largest clusters identified from our analyses but with a few small adjustments that will probably increase the feasibility of management (Figure 5). The regions we propose for consideration involve the inclusion of the largest industrial fishing ports within the fishing regions in which they are found. Ensenada (cluster 2) would be included in fishing region 1, Mazatlán and San Blás (cluster 6) would be included in fishing region 5, and Guaymas and Huatabampo (cluster 8) would be included in region 7. Although not included in our proposed arrangement of fisheries regions, we also suggest that consideration be given to moving Bahía de los Ángeles from region 1 to region 4 and Cabo San Lucas from region 3 to region 2, so that all fisheries regions would consist of geographically cohesive units.

Although some overlap exists about the harvest of a few pelagic species (e.g. yellowfin tuna, sardine, and anchovy), each fisheries region would then consist of a relatively distinct set of species groups and coastal habitats that are exploited by both small- and large-scale fisheries (Table 2). Therefore, we suggest that consideration be given to letting each fishery region institute a unique set of regulations designed to focus on species (Table 2) or areas, e.g. islands, marine reserves, watersheds, of high priority shared among the LFOs within that region. Following the philosophy of EBM, such an arrangement would facilitate more informative investigations that seek to identify the unique environmental, societal, and economic issues that each region currently faces. Specifically, such an arrangement would create a management framework capable of improving decision-making processes related to stock assessments, harvest quotas, catch shares, marine reserves, and other fisheries or conservation actions, by considering fishing activities, ecosystems, and harvested species all at the same relevant spatial scale. Similarly, a regional management system would hasten adaptive management action in relation to annual variations in stock sizes that are affected by *El Niño*/Southern Oscillation (ENSO) cycles, climate change, and other environmental parameters. Ultimately, the arrangement would help to reduce uncertainty, facilitate changes in fishing behaviour, foster the development of regional co-management with fishers, and articulate cost–benefit scenarios of different management strategies (Levin *et al.*, 2009; Cisneros-Mata, 2010).

Although the creation of a regional management system is an important step towards enhancing fishery management and administration in Mexico, many challenges remain. First, the long-range capacities and pervasive fishing activities of the five industrialized fishing ports of Ensenada, Guaymas, Huatabampo, Mazatlán, and San Blás override the regional pattern of fishing prevalent in most areas of NW Mexico. Clearly, such activities would have to be restricted for the compliance and enforcement of regional fishing policies to be effective. That statement highlights

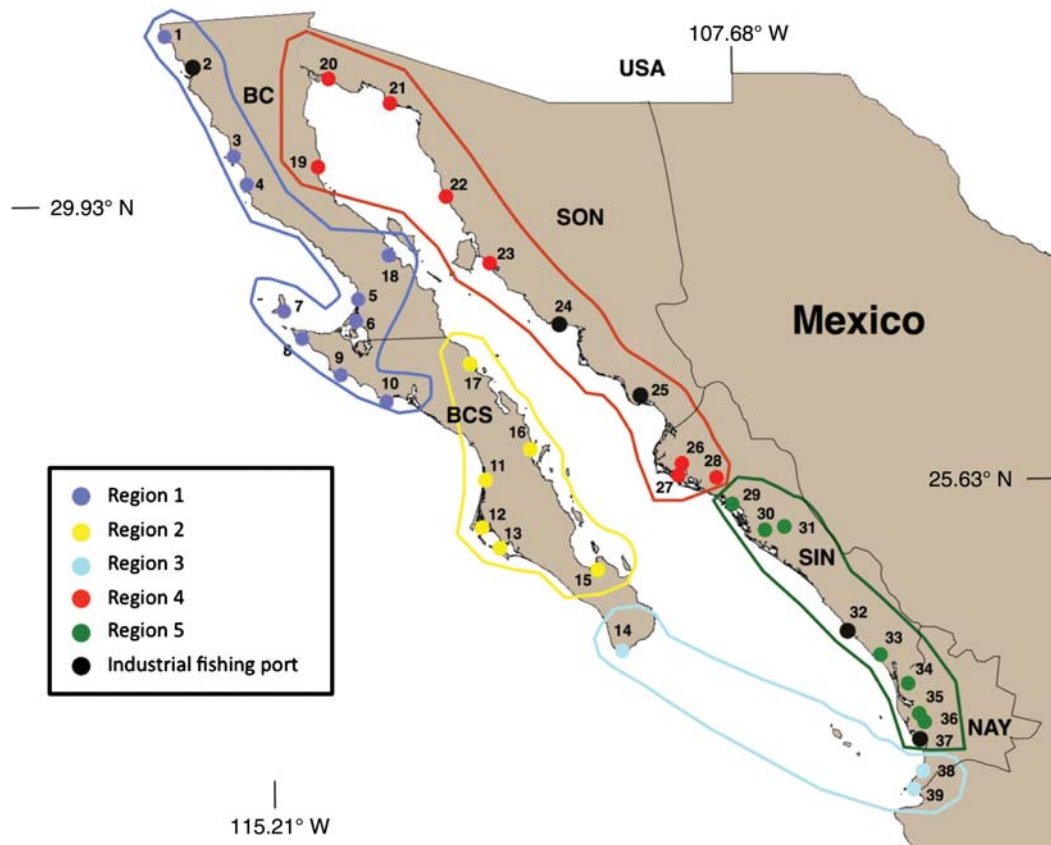


Figure 5. Map of the five proposed fishing regions for NW Mexico. BC, Baja California; BCS, Baja California Sur; NAY, Nayarit; SIN, Sinaloa; SON, Sonora.

Table 2. Qualitative list of the important species groups that characterize the coastal ecosystems and commercial fisheries of the five proposed fisheries regions in NW Mexico.

Fleet type	Fishery region				
	Region 1	Region 2	Region 3	Region 4	Region 5
Artisanal fisheries (small-scale)	Whitefish	Sea basses and groupers	Red snapper	Corvinas and other croakers	Mulletts
	Red lobster	Red and other snappers	Sharks and rays	Sharks and rays	Mojarras
	Red urchin	Red and Caribe lobster	Billfish	Blue crab	Grunts
	Billfish	Clams and oysters		Sierra	Catfish
	Sharks	Calico scallops		Rock scallop	Snook
Industrial fisheries (large-scale)	Jacks	Dorado			Blue crab
		Sharks and rays			Dorado
		Jacks			Billfish
	Bluefin and yellowfin tuna	Giant squid	Mackerel	Blue and brown shrimp	Yellowfin tuna
	Sardine and anchovies	Skipjack and yellowfin tuna	Skipjack and yellowfin tuna	Sardine and anchovies	White shrimp
	Mackerel		White shrimp	Giant squid	

a pervasive problem with the most widely used fishery-management tool for regulating access to marine resources in Mexico, the fishing-permit system (reviewed by Cinti *et al.*, 2010). The system places legal fishing rights in the hands of permit-holders, businessmen who often are not closely linked with the fishing activity or fishing community and have few

incentives to fish responsibly or to seek sustainable outcomes, because they rarely live within the region where their permits operate. Instituting legal rights for active resource users (fishers) rather than permit-holders may well be a way to control harvests locally and minimize intrusions from outside, which in turn should promote incentives for stakeholders to participate in

management decisions, comply with fisheries regulations, and engage in stewardship of marine resources and coastal ecosystems. Such rights might include granting exclusive use or property rights to shares of fisheries within defined areas, effort units, or catch to individuals, groups of individuals, or communities. Such tools have yet to be implemented on a broader institutional level in Mexico, but they have shown promising results where attempted (Cudney-Bueno *et al.*, 2009; Ezcurra *et al.*, 2009).

There is also a clear need to create stronger connections between regional and species-specific management plans under the new fisheries law, because there are considerable harvest levels of important and threatened species within designated areas such as the Gulf's growing network of marine protected areas. Finally, the success of any proposed changes in fisheries-management policies will require significant improvements in the resolution, accuracy, and consistency of official landings data and statistics. Current Mexican fisheries statistics use coarse taxonomic categories that include multiple trophic levels, and landings data give no detail on fishing effort or location of capture. As a result, the data are poor indicators of ecosystem health, are unable to detect overfishing or stock declines, or decreases in the trophic levels of catches, i.e. fishing down the foodweb, or other signs of environmental degradation (Aburto-Oropeza *et al.*, 2007; Erisman *et al.*, 2010).

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