Aerial Monitoring of Ocean Vessels in Southern California

February 2016 – Preliminary Project Report

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Thanks to our Project Partners and Supporters:

LightHawk, Vantuna Research Group, Campbell Foundation, and U.S. EPA

Project Overview

Objective long-term data on the type, extent and location of boating and boat-based fishing directly supports the success of marine spatial planning and resource management of coastal oceans. This project was initiated to generate an objective fishery-independent dataset to define the extent of boating activities in the state waters off the coast of mainland southern California. Now that a network of Marine Protected Areas (MPAs) has been established off this coast, these data allow in-depth descriptions and analyses of trends in fishing activities and compliance with the new regulations associated with this network. This information will be very useful in the adaptive management and enforcement of this network.

This project reflects the work of three partners; The Bay Foundation, LightHawk, and Vantuna Research Group.

Pre-MPA

September 1, 2008 was the first of 41 flights that accurately mapped the type, location and activity of vessels (from oil tankers to kayaks) operating in state waters of the mainland coast of southern California from Point Conception, Santa Barbara County to the US / Mexican Border. 5,304 vessels were observed and recorded during a two and one half year effort, (9/1/2008 through 4/1/2011). This objective, fisheries-independent dataset was incorporated into the South Coast Marine Life Protection Act Initiative by providing spatially specific information on the extent and type of fishing occurring off the coast. These data helped the stakeholders and decision makers involved in this process determine the locations for a network of MPAs while allowing areas valuable to fishing to remain accessible.

Post-MPA

January 20, 2012 marked the first flight following the establishment of the south coast MPA network. The same method applied pre-MPA continues to be used to describe trends and responses to the MPA network, namely from the fishing communities that have been restricted due to the MPA network. The information from this effort will be useful to decision makers, enforcement agencies, stakeholders, scientists and resource managers charged with enforcing and adaptively managing the newly established network in two ways. Firstly, as the location, type and activity of vessels are observed and collected, noncompliance with the new regulations is accurately depicted by this dataset. Locations with high rates of noncompliance are identified, which enables the California Department of Fish and Wildlife and others to engage in strategic and highly effective enforcement efforts. In addition, sectors of the fishing community with high rates of noncompliance can be addressed in similarly targeted and effective way as a fishery, independent of location. Secondly, adaptive management of this network by the dataset generated during post-MPA (when compared with pre-MPA data) will provide objectivity to this public process by specifically elucidating trends in the amount, location and type of fishing occurring post-MPA. We can anticipate a highly charged politicized environment for this process, and this type of empirical information is especially effective in countering false or misguided claims by individuals or industries.

Aerial Survey Methodology

These surveys collect spatially specific data regarding the distribution, type and activity of vessels operating in state waters following the implementation of MPAs in the south coast region. The Southern California Bight is divided into two transects; the southern transect begins south of LAX, ending at the Mexican Border and the northern transect begins north of LAX, ending at Point Conception. Small aircraft capable of high maneuverability and low speeds are used to fly directly over vessels while survey personnel accurately record location, vessel type, activity, and (when possible) a photograph. Depending on weather conditions, aircraft fly at an altitude of 500 to 1000 feet (average elevation for pre-MPA equaled approximately 650 feet) and travel at 100 to 120 knots. LightHawk coordinates volunteer pilots and their aircraft to complete the surveys. The collection of data from small fixed-wing aircraft allow for a transect to be completed in approximately two to two and one half hours depending on number of vessels encountered and other factors e.g., weather, airspace restrictions.

Aerial survey team comprising; pilot (front left), spotter (front right), GPS technician (back right), Image collected courtesy of LightHawk.

The survey team consists of a pilot, spotter, GPS technician and photographer. Some of the planes are incapable of carrying a pilot plus three passengers; in this circumstance, the photographer role is adopted by the spotter. The spotter directs the pilots' flight path to intersect the vessels on the water, describes the type and activity of the vessel at time of contact and directs the GPS technician to enter a point and corresponding information into the computer. When possible, the photographer captures a photograph of the vessel(s) to aid in post flight QA/QC (Quality Assurance Quality Control). Due to the speed of the aircraft, rapid and accurate identification of vessels encountered on a transect is required. Therefore, the spotter, aided by binoculars or telephoto camera lens, must be familiar with the various boat types and activities boaters engage in, in the south coast region.

This information is recorded by the GPS technician into one of the predefined categories (Commercial Fishing, Commercial Non-fishing or Recreational) in a GPS data dictionary along with observed vessel type and activity (underway, fishing or anchored/not fishing), date, time, and any relevant notes. Ideally, vessel positions are not logged until survey planes are directly overhead for highest spatial accuracy. In areas with high vessel density or restricted airspace, where logging vessels individually is infeasible, multiple boats may be logged to a single representative point and later extracted using GIS.

Table 1. This table illustrates the relationship between the data categories. The broad Vessel Categories are typically noted first, then the finer scale Vessel Type, lastly an Activity is assigned. This information is entered along with geographic coordinates to accurately characterize the location, type and activity of vessels operating in the 990 square miles of California State Waters off the mainland coast of Southern California.

Vessel Categories		Vessel Type
	Commercial	CPFV
	Commercial	Lobster Boat
	Commercial	Trap Boat
	Commercial	Urchin Boat
	Commercial	Trawler
	Commercial	Purse Seiner
	Commercial	Light Boat
	Commercial	Gillnet
	Commercial	Other

Vessel Categories		Vessel Type (cont.)
	Commercial	Passenger Boat (Ferry, Cruise ship, Booze cruise)
	Commercial	Tanker
	Commercial	Cargo Ship (Barge, Container)
	Commercial	Support Vessel (Tug, Tender)
	Commercial	Res-Mil-Enf (All Science and Gov't Boats)
	Commercial	Charter (Whale watching, Diving)
	Commercial	Other (Dredge, parasail, etc.)
	Recreational	Sport Fishing Boat
	Recreational	Power Boat
	Recreational	Sailboat
	Recreational	Dive Boat
	Recreational	Kayak
	Recreational	Jet Ski
	Recreational	Other (SUP, outrigger, row boat, etc.)

Activity	Fishing
Activity	Underway
Activity	Anchored

Data Handling and QAQC Methodology

After completion of the aerial survey, the GPS data are downloaded to Pathfinder Office, then exported into ArcGIS for analysis. Any photos taken of the vessels are linked to the corresponding data points collected and used for post-flight QAQC and training purposes. All entries with incomplete data were excluded. Additionally, all points with entry errors, such as inconsistencies between boat type and vessel type, were revised. As a result, consistent naming and classification conventions were kept between years. Once these data have been verified as accurate through QA/QC processes, the information is updated to the entire dataset from which maps and statistical analyses are derived. Additional descriptive fields are assigned to the dataset, including project year, Pre or Post-MPA classification, and transect direction (North or South) for later analysis.

Error Calculation

A certain degree of error is inherent in the collection of fine-scale spatial data from a moving aircraft. In order to quantify this error, a series of calibration points were collected during flights. Fixed objects with known coordinates, such as piers or oil platforms, were recorded. These observed locations of the calibration points were then matched with each point's actual GPS coordinates, and a distance between the two was calculated in ArcGIS. These distances between observed and actual were then averaged together to produce the mean error of observations, which was estimated to be 191.16 meters. This error was then incorporated into many components of the analysis. The study area of the California Coastal Waters was extended by observed margin of error, and all points falling outside of this boundary were excluded.

Summary Statistics

The summaries following are drawn from data collected by this effort. Data collected between 2008 and 2011 were consolidated as a Pre-MPA assessment. Subsequent surveys were conducted from January 2012 to September 2015. These surveys were examined both annually and grouped as a Post-MPA classification. The spatial and temporal variability of these data were then examined to inform broadly the distribution of boating effort in the Southern California Bight using ArcGIS, R, and Systat software.

General Summary Statistics

Table 2. Total vessel observations and number of flights by project year.

Time Interval	Total Vessels Observed	Number of Flights/Transects
Pre-MPA Total (Sept 2008-April 2011)	4567	39
Year 1 (Jan -Dec 2012)	4197	28
Year 2 (Jan-Dec 2013)	2742	22
Year 3* (Jan-Dec 2014)	1421	9
Year 4 (Jan-Sept 2015)	399	4
Post-MPA Total (Jan 2012-Sept 2015)	8759	63

*Beginning in June 2014, the survey interval for the study was switch from monthly to quarterly.

Table 3. Total number of vessels observed by transect.

Transect	Total Vessels Observed
North	3265
South	10061

The number of flights flown for each transect direction (north/south) varied slightly both within and between years. As a result, in order to compare variables or observations between years, all data was normalized for survey effort. Total observations were divided by the number of flights flown for that transect and year to determine the average observations per flight. These averaged values were subsequently compared to determine trends in the data.

The density-number of boats operating on the Southern Transect from Los Angeles to the US Mexican Border is significantly greater than the density on the Northern Transect from Los Angeles to Point Conception. We found this reduced density of vessels on the northern transect of the study area to be a significant driver of many relationships explored in the analysis.

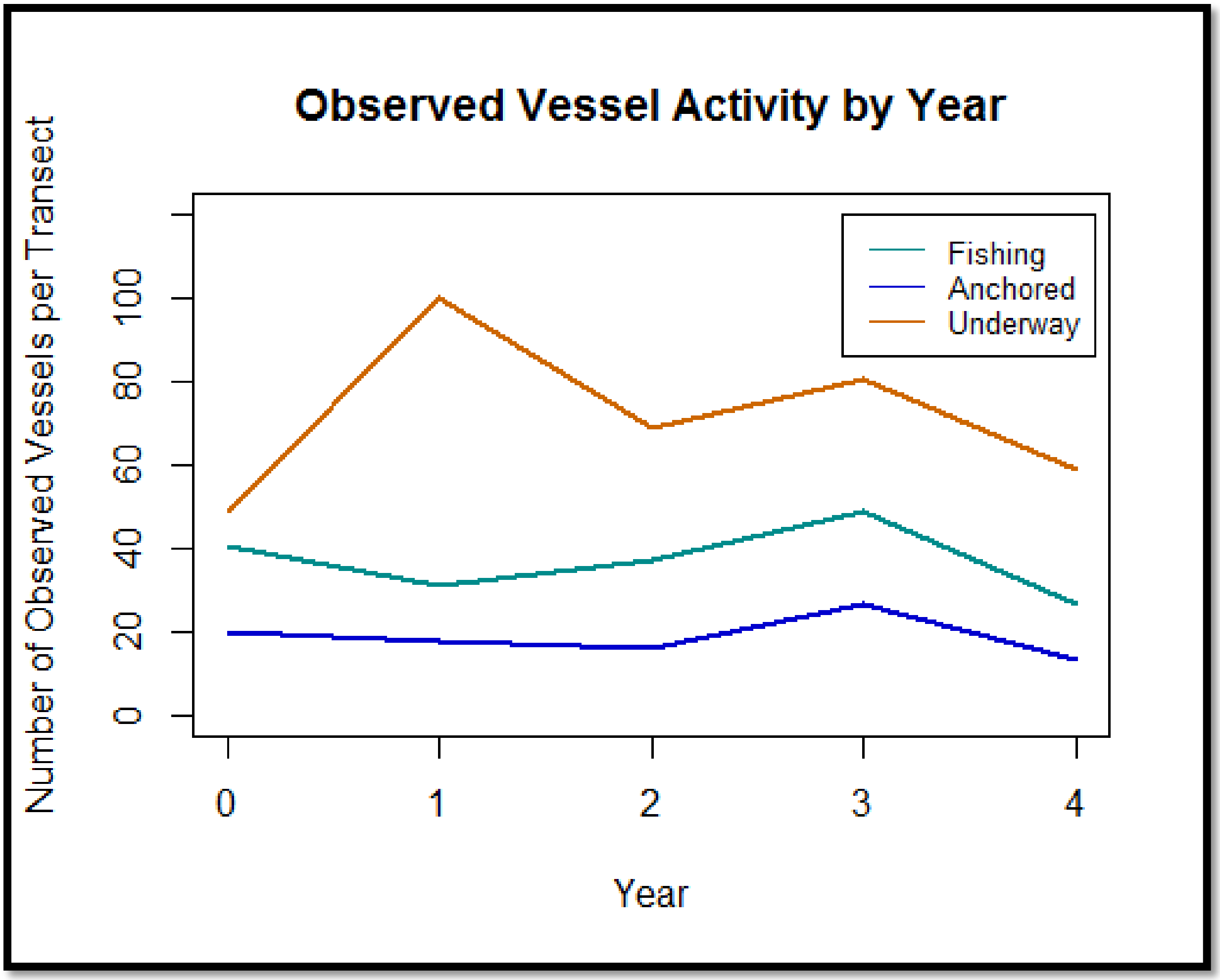

Figure 1. Examining the distribution of vessel activity by year, we found that while there was some annual variability, the relative distributions of each activity were fairly consistent. Far more boats were observed underway, followed by fishing, with the least number of boats observed at anchor. (Note: For much of the analysis Pre-MPA data was grouped together, and represented numerically as Year “0”)

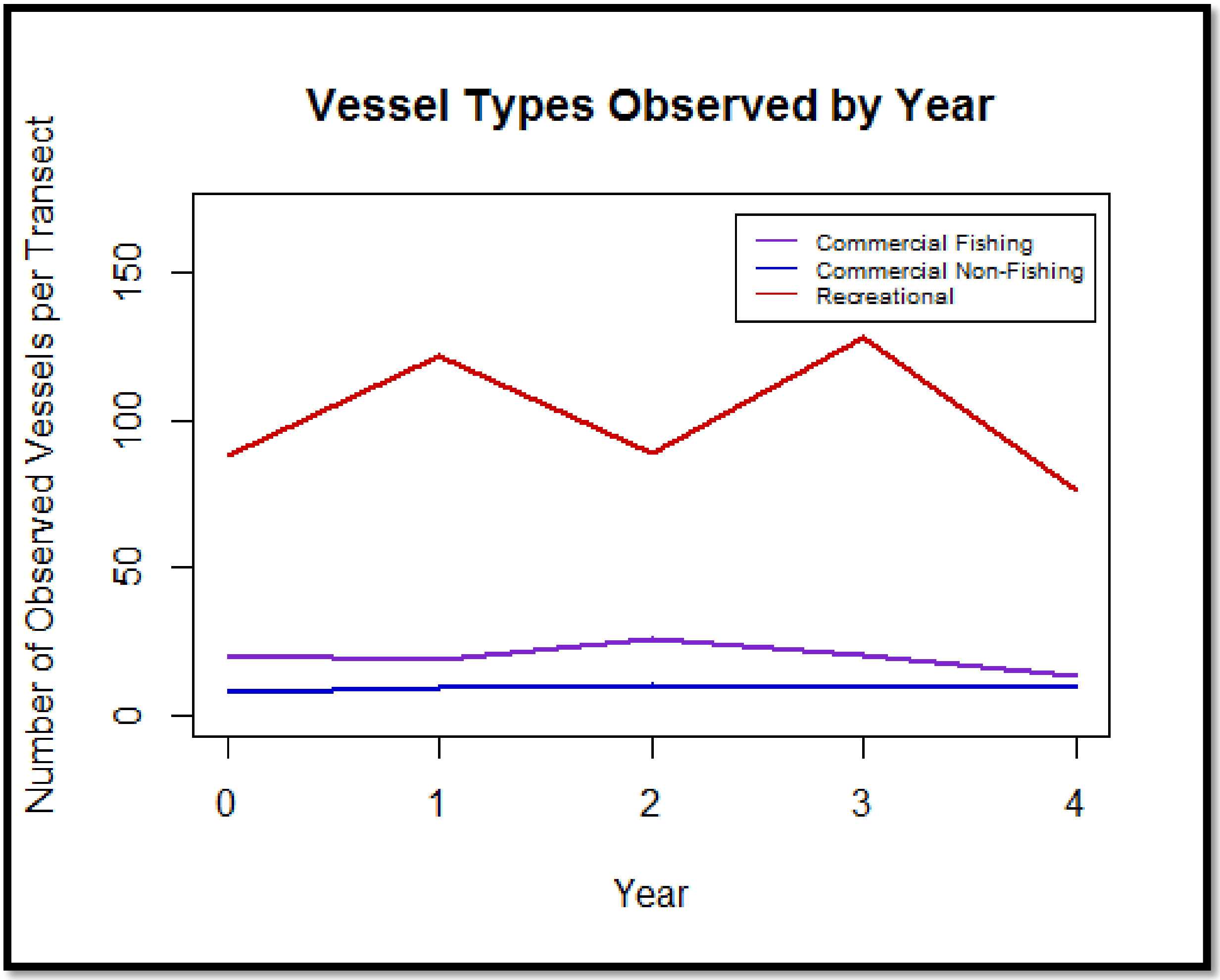

Figure 2. A similar trend was found when examining the types of vessels observed each year. Recreational boats are by far the most common, with Commercial Fishing and Commercial Non-Fishing recorded significantly less frequently. Commercial and Commercial Non-Fishing vessels tended to be recorded with far less year to year variation. This is likely due to the purpose of these vessels operations, and are therefore less impacted by ocean conditions, fuel prices, days of the week, or other variables that would discourage or alter recreational boat use.

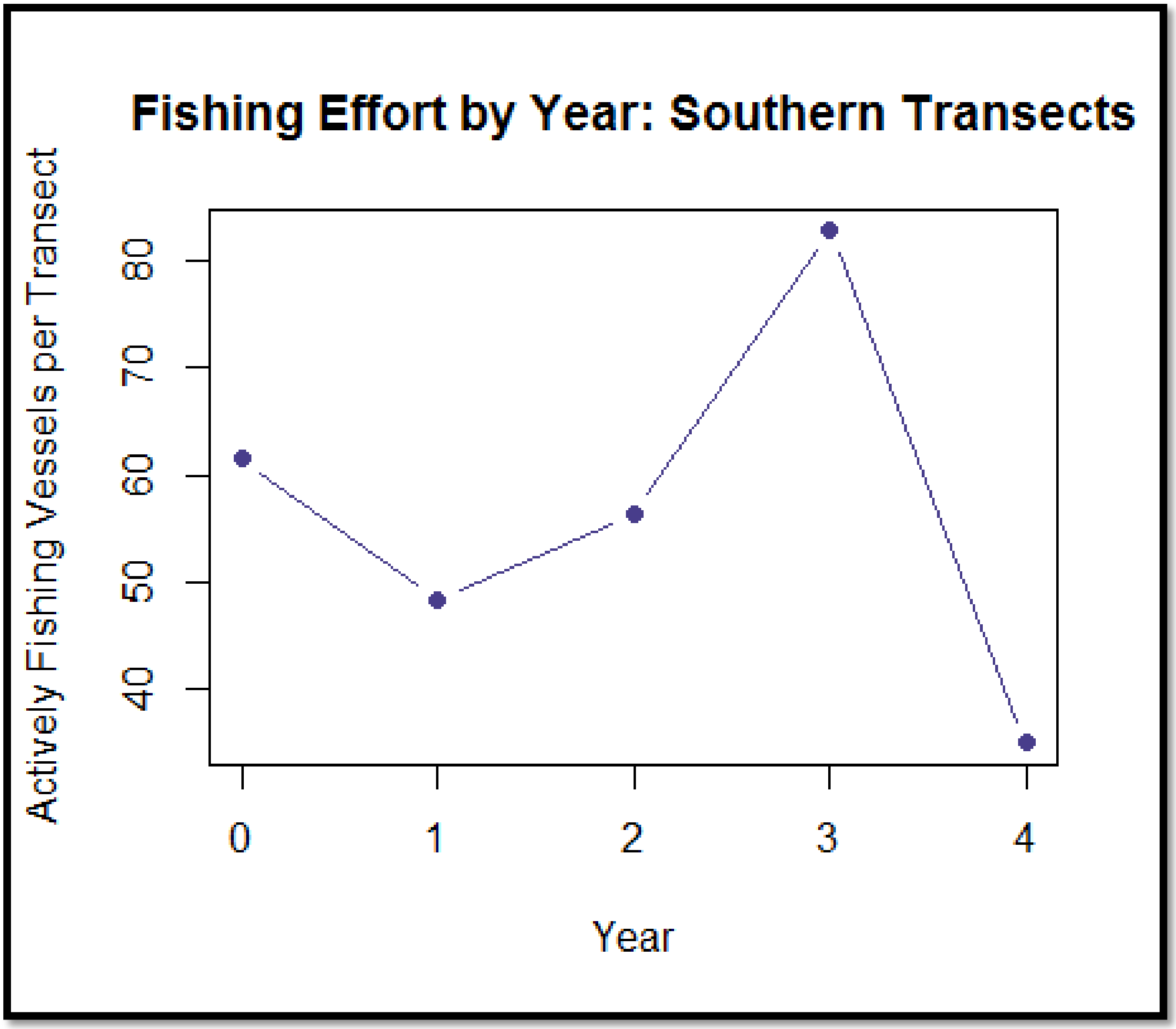

Figure 3. Given the differences in fisheries, substrate distribution, MPA locations, ocean conditions, and sheer numbers of fisherman, fishing effort was compared separately between northern and southern transects. Fishing effort and density of fishing vessels were found to be much greater in the south. With an average of 56.84 vessels observed actively fishing per transect each year.

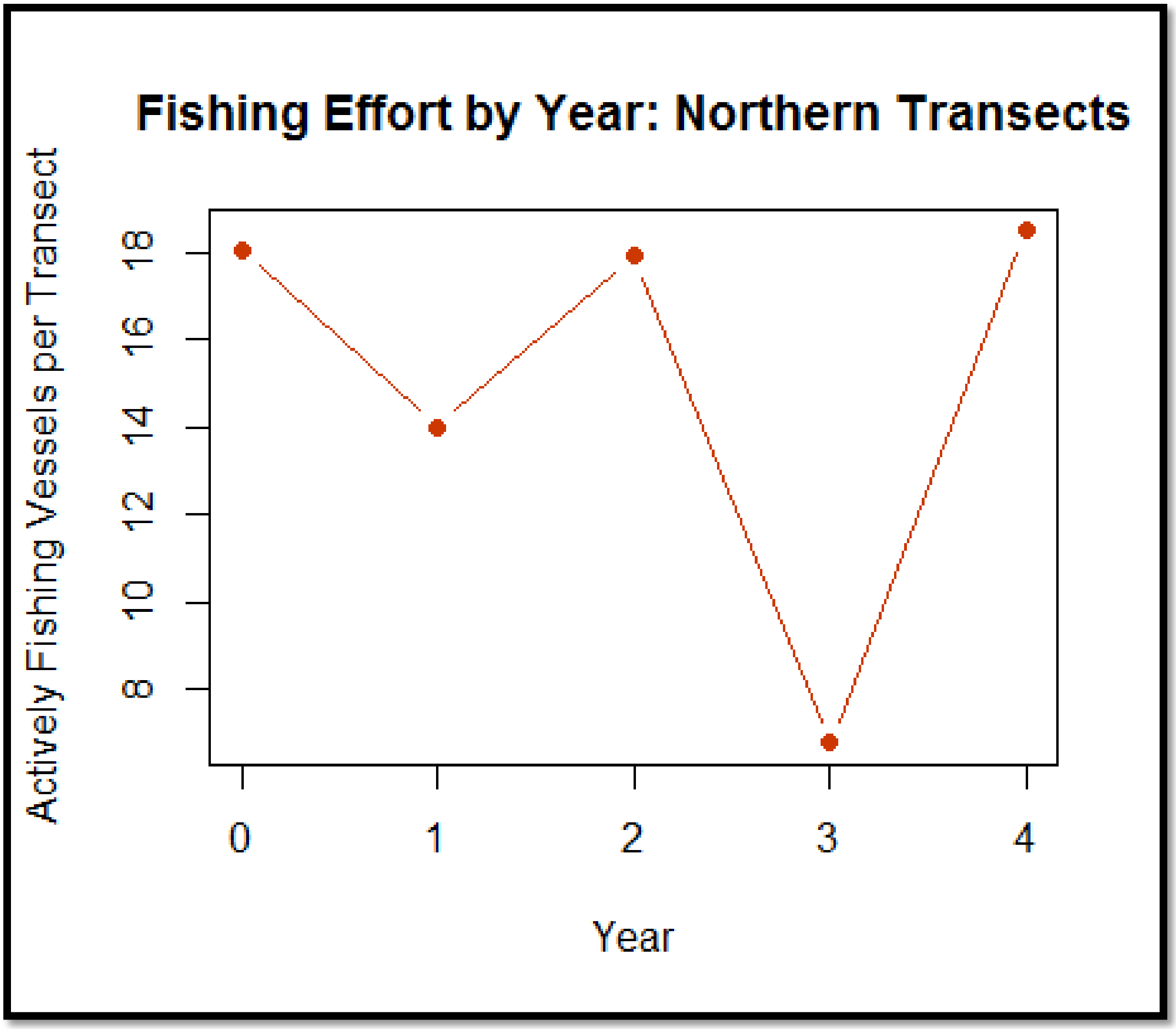

Figure 4. The mean fishing effort of northern transects was significantly lower, with an average of 15.04 boats observed fishing per transect through the years.

SUBSTRATE

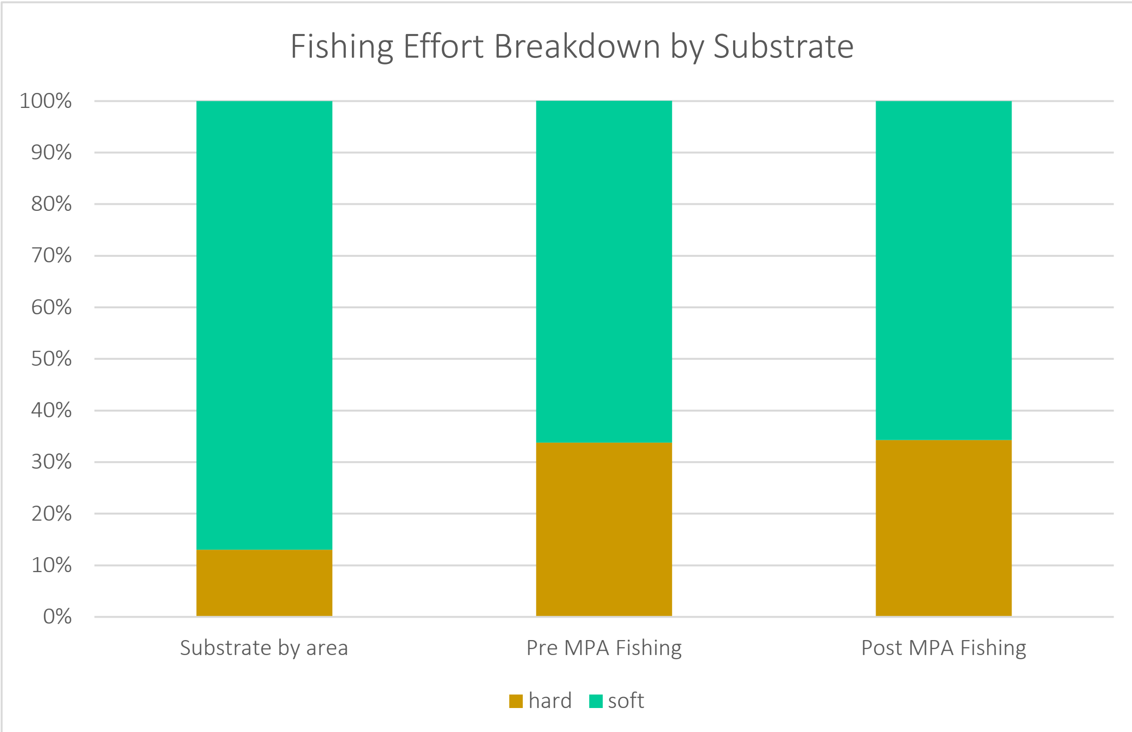

Figure 6. 13% of the study area of composed of rocky bottom, charaterized for the analysis as hard substrate, 87% is sand, mud, thusly soft substrate. Approximately 33% of the total fishing effort Pre and Post-MPA was determined to occur on this hard substrate, despite the fact that it comprises only a small portion of overall area. We found substrate type to correlate strongly with other factors explored in the analysis.

Spatial Analysis of Fishing Effort

The point data of fishing vessels were overlaid to polygons with uniform area to provide a better visualization of large-scale trends in the spatial distribution of fishing effort before and after MPA implementation. Hexagons with 1km sides (2.6km Area) were selected because they were most easily interpreted. Points falling anywhere within a polygon were summed and then normalized by transect count. The difference between Pre and Post-MPA values was determined, resulting in the change in effort for each polygon before and after MPA implementation. See Figures 10-12 on pages 18-20 for maps illustrating these changes in fishing effort near Point Dume, Palos Verdes, and La Jolla. It is important to note, that given the observed area, all recorded points could fall within 191.16 m of their recorded location. Therefore, there is likely some error associated with the assigned polygon values. As shown in the figures, fishing effort has in large part moved outside of MPA boundaries since implementation in January 2012.

Compaction

One major concern for the establishment of MPA's is the potential for the compaction of fishing vessels as they are displaced from historical fishing grounds following implementation. In order to quantify this compaction, the distance between each "fishing point" to its nearest neighbor was calculated for each transect. These distances were then log(x+1) transformed to normalize the data. ANOVA's were then run on the relationship of the distance between points and project year, controlling for a number of variables. It is important to note that compaction is directly inversely related to this metric of distance between points, with lower distances signifying greater compaction.

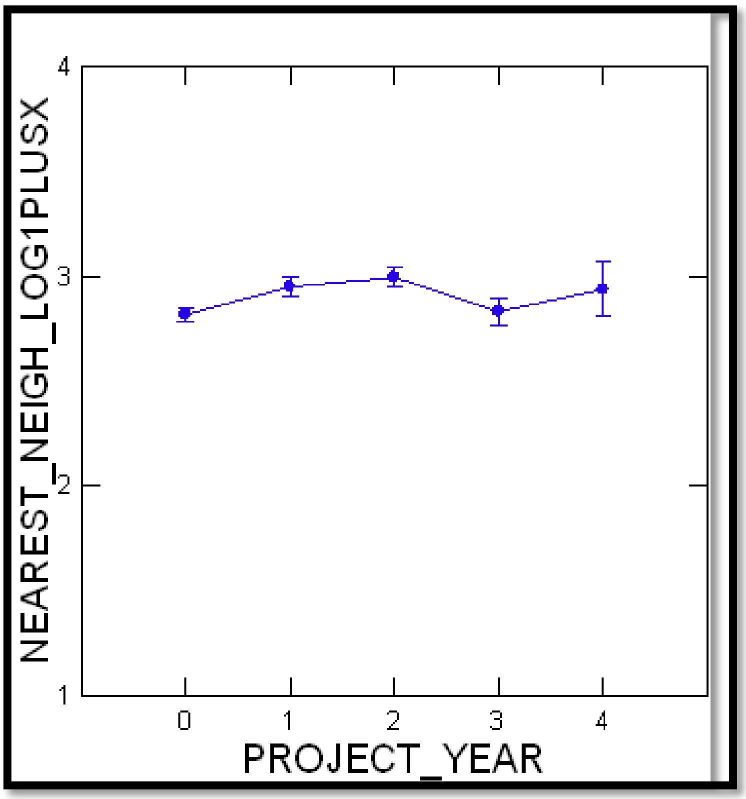

Figure 7. Average distance between fishing vessels for all transects and vessel types by project year.

The distance between points was found to vary with project year over the entire study area for all vessel types, with years 1 and 2 significantly greater than both Pre-MPA and year 4. The Pre-MPA and Year 3 distance values were found not to be statistically differ from each other, and appear to be similar. This trend suggests that rather than increasing compaction, the implementation of MPA's actually decreased compaction as vessels presumably spread apart searching for new fishing grounds. Once these new productive fishing grounds were discovered, it appears that compaction begins to increase again as fisherman aggregate on these more desirable locations. Given the relative distance values of the Pre-MPA and Year 3 subsects, it seems that this process has so far resulted in similar compaction as before the MPA's were implemented. Thus if concerns regarding compaction of fisheries informed the size, location and regulations of the South Coast MPA network; the current network appears to have not forced greater compaction. This trend holds between commercial and recreational vessel types, however, with the peak in distance occurring 1 year earlier among the commercial fishermen. It can be inferred that commercial fisherman fish much more often, and possess a greater incentive to discover the most productive ground. These functions may be influential in driving the speed and magnitude of changes between recreational and commercial fishing sectors to the establishment of the MPA network.

Vessels fishing hard substrate were found to be significantly more compacted than those fishing soft bottoms. Given soft substrate makes up 87% of the study area, those fishing there would have a much larger area to distribute over. Finally, those boats fishing the southern transects were found to be significantly more compacted than those fishing in the north, likely due in large part to fact that vessel traffic is nearly three times as high over an approximately equivalent area.

Fishing Effort Relative to MPA's

In analyzing spatial aspects of fishing effort, changes in fishing trends around newly-implemented MPA's were explored. The distance between each actively-fishing point and the nearest MPA was calculated, and normalized (log(1+x)). As with the compaction metrics, the relationship between the distance of boats from MPA's and project year was analyzed with two-way ANOVA's.

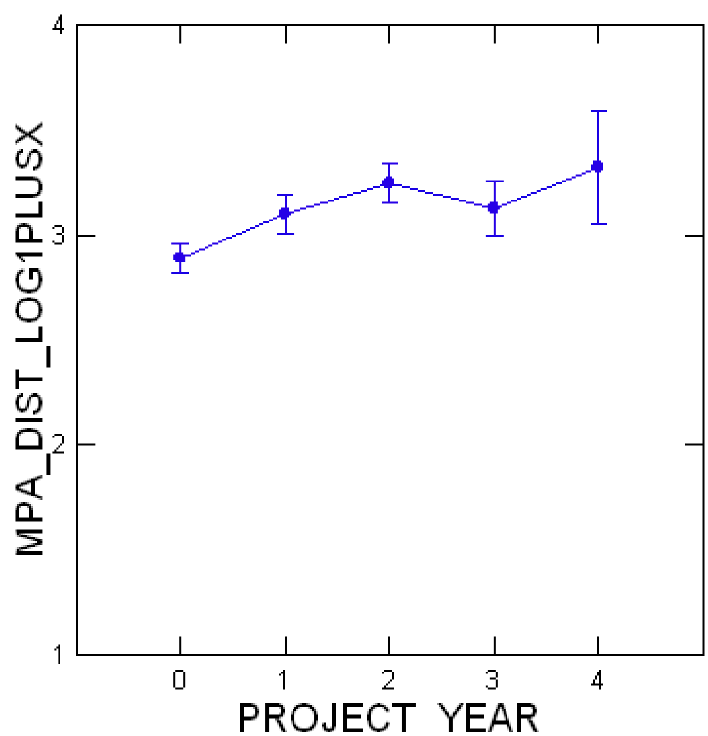

Figure 8. Average distance between fishing vessels and nearest MPA for all transects and vessel types

The distance between fishing vessels and the nearest MPA was found to be significantly greater for all Post-MPA project years (1-4) than for the Pre-MPA years. This suggests with the implementation of MPA's, vessels began to fish further away from MPA boundaries than they had previously, and have remained there through time.

The average proximity of fishing to the boundaries of MPA was found to be significantly greater for the northern transects than southern; clearly describing that boats are fishing closer to MPA's in the south than in the north. This is possibly due in large part to the greater number of both ports and MPA's south of LAX, leading to much greater proximity of fisherman fishing close to port and MPA's. Finally, boats tended to fish significantly farther from MPA's when fishing soft substrate than when fishing hard substrate for northern transects, while there is no significant difference in the south. This is likely an artifact of the relative differences of MPA distribution relative to substrate in the north and south portions of the Southern California Bight.

MPA Compliance

One of the major objectives of the project was to investigate compliance to MPA regulations following their implementation in 2012. In order to examine compliance, the spatial border of each MPA was reduced by our determined margin of error. We could then be confident that all points that intersected this minimized MPA polygon in reality fell within MPA boundaries. Next, the classification of each MPA was referenced for take restrictions. When collecting data, only those boats with a visible fishing line in the water or fishing gear on deck in use are deemed actively fishing. Referencing these criteria, vessels were deemed compliant, non-compliant, or undetermined. All undetermined vessels were excluded, resulting in a subset of boats that are indisputably in direction violation of MPA regulations, and therefore constitutes a conservative estimate. These non-compliant vessels were then compared to the total number of vessels recorded that year to calculate a percentage score of compliance.

Table 4. Count and Percentage of Non-Compliant Vessels by Year

Year	Non-Compliant Vessels	Percentage of Non-Compliant Vessels
1	37	4.23%
2	18	2.20%
3	12	2.72%
4	1	0.93%

We found a steady decline in violations of MPA regulations with time as. The commercial fishing sectors that were observed displayed compliance with the new regulations with very few exceptions. Nearly all noncompliant boats were recreational vessels, with sixty recreational boats observed out of compliance, compared with only eight commercial fisherman. This is likely due both to greater awareness of commercial fisherman to regulations, and the impact of penalties, i.e., fines, jail terms, and loss of licenses for commercial poaching. In general, non-compliance seems to be limited, given the increasing low occurrences of violations when compared to fishing trends more broadly.

Table 5. Non-Complaint Vessels Sighted by MPA all years Post MPA implementation.

MPA Name	Non-Compliant Vessels
South La Jolla	17
Matlahuayl	14
Laguna Beach	10
Swami's	9
Point Vicente	6
Point Conception	4
Naples	3
Campus Point	3
Tijuana River Mouth	1
Cabrillo	1

The highest incidents of non-compliance collected by this effort are found off the coasts of San Diego and Orange County. Almost 60% of all violations, either non-compliance or willful poaching have been described in South La Jolla, Matlahuayl, and Laguna Beach.

Further examination of the attached maps regarding changes in fishing effort around MPA's can also inform compliance. Examination of Figure 12 relating to changes in fishing effort around the La Jolla MPA, shows a polygon completely contained within the MPA border reporting an increase in fishing effort with MPA implementation. This suggests a potential for a high degree of non-compliance within this region and should be a priority for enforcement agencies.

Non-Consumptive Uses of MPA's

Of equal importance to the potential impact of MPA's on fishing practices, is the increased potential for non-consumptive recreational uses within these new areas. In order to explore the response of non-consumptive recreational boats to the implementation of MPA's, we examined the average distances of these vessels to MPA's with a similar methodology to the examination of boat based fishing effort i.e., consumptive uses. Non-consumptive recreational boats were classified as all recreational powerboats, sailboats, dive boats, kayaks, jet skis, or other (outrigger, SUP's, etc.) not actively fishing. The distances between these vessels were calculated, and averaged by project year.

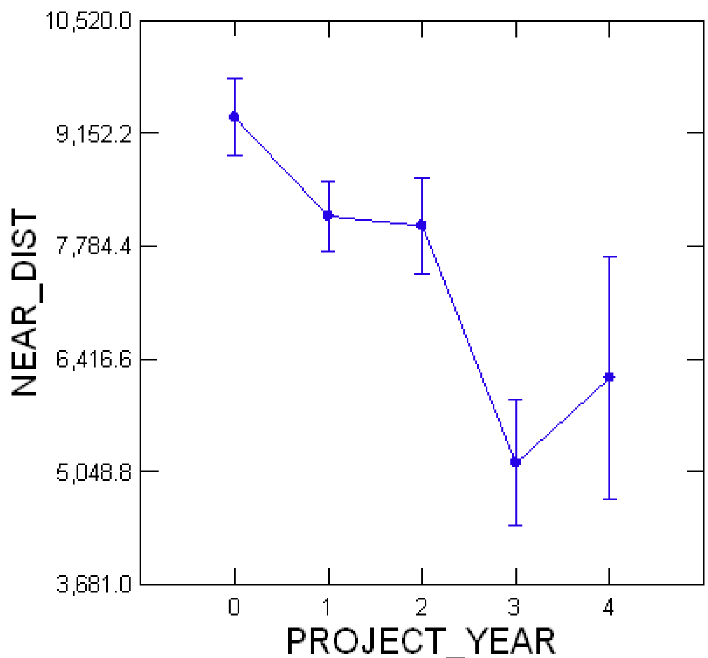

Figure 9. Average distance between non-consumptive recreational vessels and nearest MPA for all transects and vessel types.

We found the distance between non-consumptive recreational vessels and the nearest MPA to decrease significantly once the MPA's were put in place. This significant decrease suggests that these vessels are recreating much closer if not within MPA boundaries.

Figures 10-12. The following figures display the change in fishing activity around MPA's located around Palos Verdes, La Jolla and Point Dume with MPA implementation referenced in the "Spatial Distribution of Fishing Effort" Section.

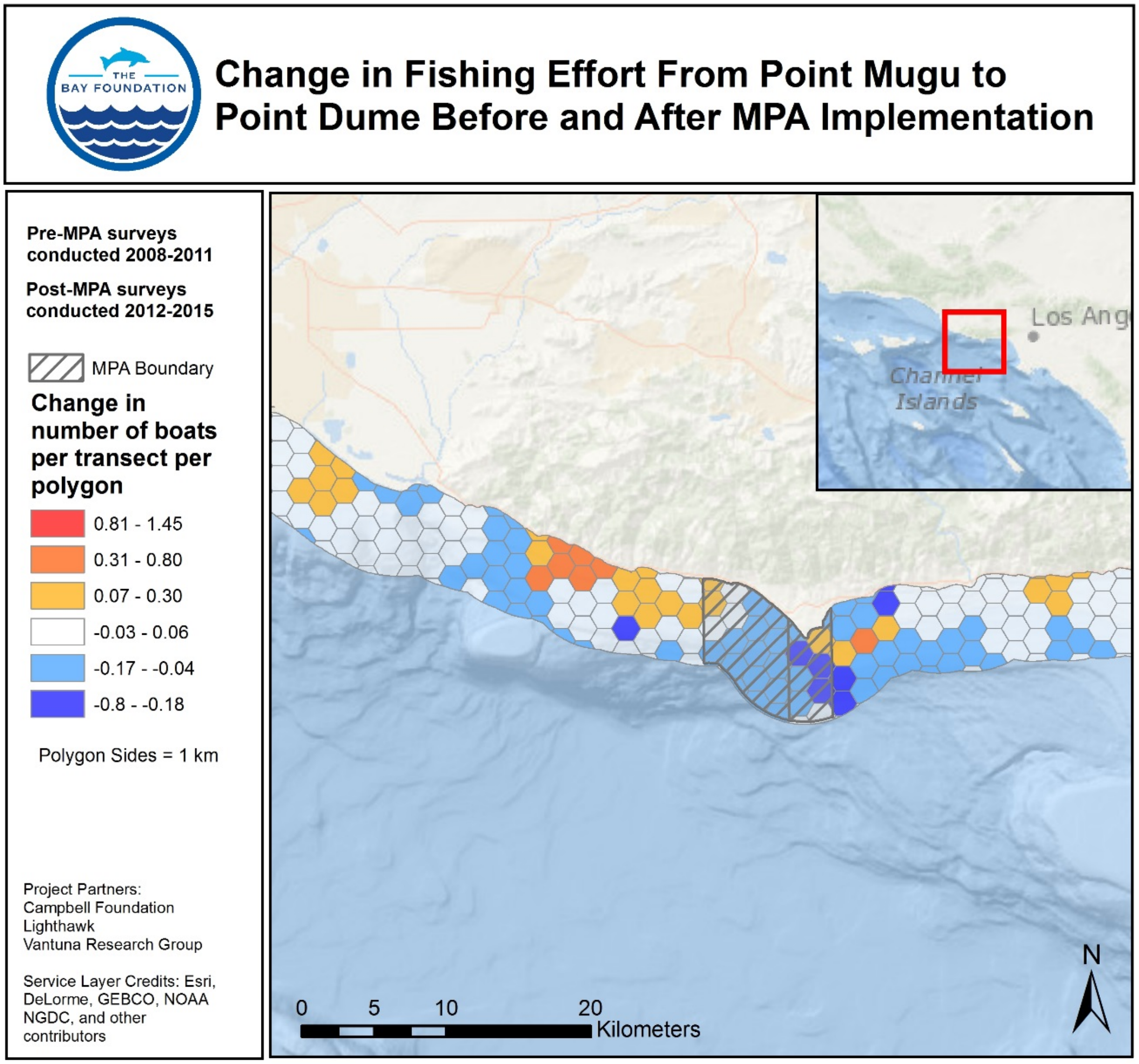

Figure 10. Change in fishing effort with MPA implementation: Point Mugu to Point Dume

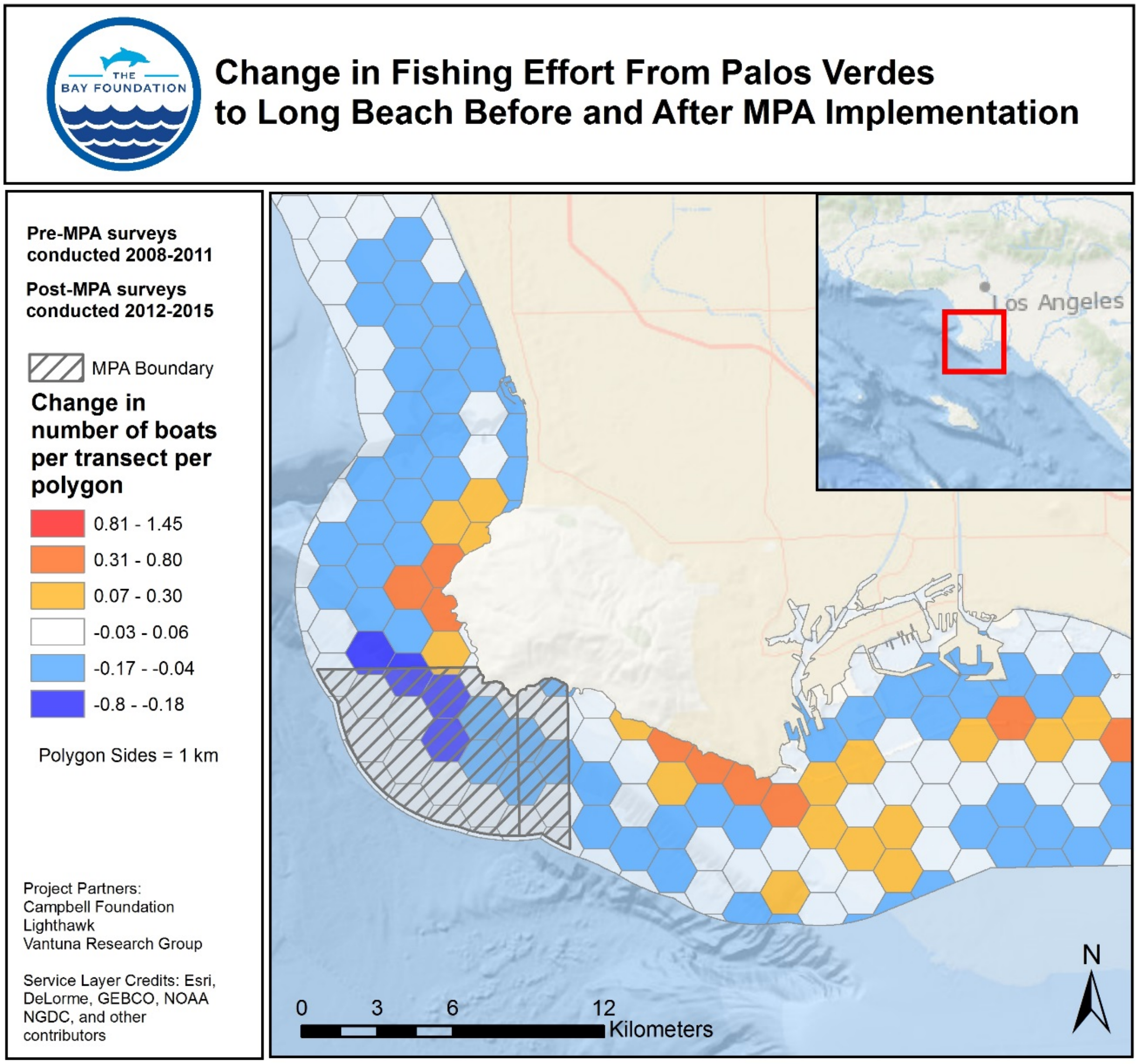

Figure 11. Change in fishing effort with MPA implementation: Palos Verdes to Long Beach

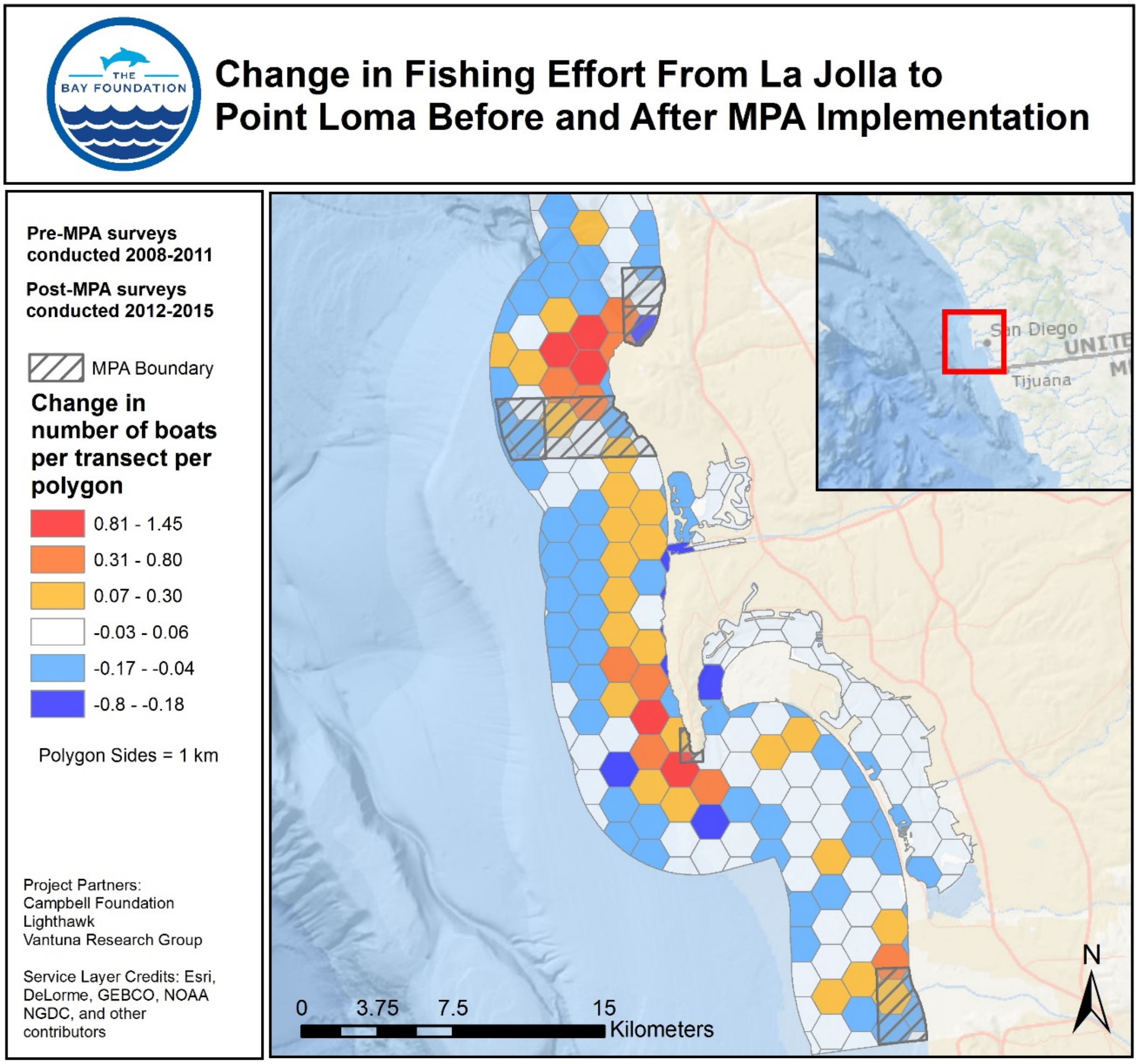

Figure 12. Change in fishing effort with MPA implementation: La Jolla to Point Loma

Discussion

The data collected by this effort have supported analyses that describe significant values to human responses to the establishment of the South Coast MPA network. In many cases this objective fishery-independent dataset and data products reveal positive socioeconomic trends. In summary, the rate(s) of boating and overall commercial and recreational fishing effort(s) along the mainland coast have remained steady despite the implementation of MPAs. The data also suggest that boaters have responded to the implementation of MPAs. Commercial fishermen moved well away from the boundaries of the MPAs and that trend has continued through September 2015. So the effective boundary of the MPAs in regards to commercial fishing, in reality suggest that MPAs are functionally larger than they exist on a map or chart. Numerous factors are likely to contribute to this as habitat continuity along the border may be lost i.e., no hard substrate extends to or beyond the boundary of a given MPA, thus fishing specific to that bottom type is essentially lost. The lag associated with biological production e.g., increased species richness, and biomass responsive to MPA protections will limit the spillover benefits to fishermen interested in the direct benefits of MPAs to fishery management. In short, there may be limited or no benefit to “fishing the line” in the early years following MPA implementation. Interestingly, non-consumptive boating has increased within and in proximity to MPA boundaries which mirrors trends described in the Northern Channel Islands within the first five years of the establishment of MPAs within the archipelago.

Compaction of fishing effort due to the loss of fishing grounds resulting from MPA implementation was a noteworthy concern frequently voiced during the designation of MPAs in Southern California. Our data describe and initial expansion of fishing effort; meaning the space between vessels observed fishing increased during the first years Post-MPA. In 2014-2015 the distance between vessels has decreased exhibiting a rate of compaction that is roughly equivalent to the distance between vessels that existed within the 990 square miles of our survey area Pre-MPA. In summary the vessels observed fishing are spaced out much the same as they were in the years preceding the delineation of the MPAs.

Education and enforcement of MPA regulations is central to the manifestation of benefits associated with MPAs. If high rates of non-compliance or poaching continue to negatively impact the intended increases in species richness and biomass for fishes, invertebrates and other species then the MPAs will not be effective over time. Our data display high rates of compliance that are improving over time. Our results describe a stepwise decrease, a reduction by half from year one i.e., 2012 to 2013 and half again from 2014 to 2015. These results are encouraging and suggest that the fishing community is aware and in aggregate responding positively to the regulations established by MPA implementation along the mainland coast of Southern California. Our observations are limited to daylight conditions with little or no coastal fog, these factors may skew our data and actual non-compliance and poaching rates could be different by location and time based upon numerous factors.

Several overarching trends described in this dataset that have held true over the years, namely that there is a greater density of boats operating to the south and east of Los Angeles, from Palos Verdes to the US Mexican Border, than there are north and west of Los Angeles from Malibu to Point Conception. Independent of density, our observations describe rates of non-compliance that are significantly greater within MPAs located in San Diego, Orange and Los Angeles Counties than those in Santa Barbara. Lastly, the preference of anglers targeting hard bottom rather than soft bottom remains consistent over time despite 87% of the coastal waters of Southern California consisting of soft bottom.