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Converting Waste Into Resources

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VIA ELECTRONIC MAIL

Ms. Renee Purdy, Executive Officer
California Regional Water Quality Control Board
Los Angeles Region
320 W. 4th St., Suite 200
Los Angeles, CA 90013

Attn: Information Technology Unit

Joint Water Pollution Control Plant
CI No. 1758; Resolution R019-001; NPDES No. CA0053813
Effect of Diel Variation on Evaluations of Ecological Condition of Demersal Fish Assemblages in Southern California Coastal Waters, 1979–1990 (JWSS-19-002)
<u>Special Study Final Report Submission</u>

Per Order No. R4-2017-0180 and Resolution No. R019-001, adopted by the Los Angeles Regional Water Quality Control Board (Regional Board), please find the enclosed draft manuscript for submission to a scientific journal that serves as the final report for the subject special study:

Effect of Diel Variation on Evaluations of Ecological Condition of Demersal Fish Assemblages on the Southern California Coastal Shelf

This manuscript is a pre-submittal draft and is subject to continued review and editing by the authors prior to or after submission for publication. Unless otherwise instructed by the Regional Board or Regional Board staff, this will be the final submission associated with this Special Study. However, a final version of this manuscript and any other reports or peer-reviewed publications resulting from these studies will also be provided to Regional Board staff as they become available.

Very truly yours,

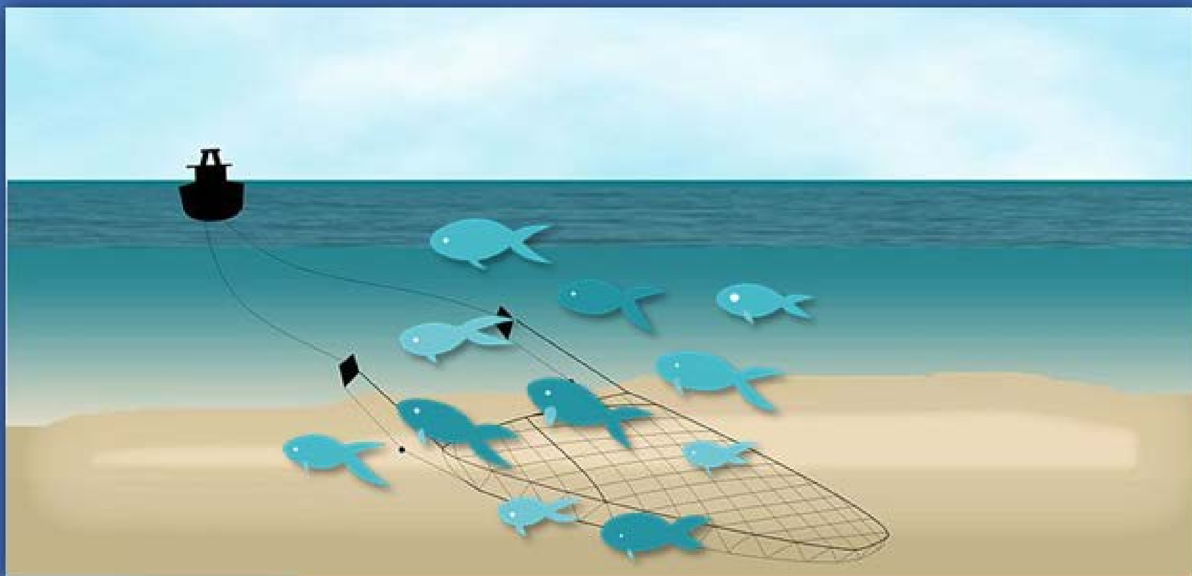
Lysa Gaboudian

Lysa Gaboudian
Supervising Engineer
Reuse and Compliance Section

EB:LG:SW

DOC# 6417509

Joint Water Pollution Control Plant
CI No. 1758; Resolution R019-002;
NPDES No. CA0053813



Effect of Diel Variation on Evaluations of Ecological Condition of Demersal Fish Assemblages in Southern California Coastal Waters, 1979–1990 (JWSS-19-002)

Final Report
December 2021

CALIFORNIA STATE UNIVERSITY FULLERTON

LOS ANGELES COUNTY SANITATION DISTRICTS
Converting Waste Into Resources

Draft Manuscript:

Effect of Diel Variability of Demersal Fish Assemblages on Evaluations of Ecological Condition on a Southern California Coastal Shelf

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ABSTRACT: Multiple bottom trawls for collecting demersal fish were conducted at different times of year over the period from 1979 to 1990. For a particular sampling period, 2 replicate trawls were conducted at multiple depths and distances from shore, repeated at 4 different times of day. From these trawls, the abundance and size class of all individual fish species were counted. Using these data, the differences in abundance, size class, and multiple measures of community ecology versus time of day during which the trawl was conducted were examined. The effect of season, bottom depth, presence of El Niño, or other hydrographic variables also varied in the calculation of these metrics as a function of time of day. Time of day was found to have a large impact on the abundance of fish caught in trawls for depths ranging from 21 m to 100 m, although less so at 100 m. There was no difference in abundance for trawls conducted at 6 m in the very nearshore region. Calculations of various community metrics were also affected by the time of day of the trawl, most notably, those metrics which rely heavily on abundance as part of the calculation, since abundance was so drastically affected by time of day. There were no apparent trends of time-of-day effects on community metrics associated with sea surface temperature (SST), El Niño, or season. This study provides a critical revelation that time of day is a factor that should be considered if there is a difference between stations not otherwise explained by other factors such as climate regime, particularly for trawl stations at the inner and mid-shelf depths.

KEY WORDS: Bottom Trawling, Demersal Fish, Community Composition, Spatiotemporal Patterns, Resource Management, Southern California Bight

1. INTRODUCTION

In the Southern California Bight (SCB), there are numerous local and regional long-term monitoring programs designed to examine the effects of climate variability and anthropogenic impacts on the abundance and community structure of fish which are a critical marine resource within the region. The ecology of coastal demersal fishes in Southern California has been regularly documented for decades using trawl surveys to assess climate change and anthropogenic impacts through analyses of community structure and the use of fish health indicators. Publicly-owned treatment works (POTW) ocean dischargers have been conducting such assessments along the SCB since 1972 for local and regional SCB monitoring programs. Trawl surveys of fish and invertebrate communities used in most monitoring programs are typically conducted during daylight hours. However, fish have relatively high visual acuity, are often strong swimmers, and are known to be able to avoid nets. Some fish species are known to exhibit diel patterns where they reside, e.g., in beach shoreline habitats, and larval fish can also undergo diel migrations (Allen et al., 1983; Findlay and Allen, 2002). Previous work has shown clearly that many species of fish (and invertebrates) avoid nets during the day and are easier to catch between dusk and dawn (Morrison et al., 2002). Though much is known about fish patterns during the daytime hours, there is limited information on diel demersal fish community patterns in the SCB and the potential impact that these patterns could have on resulting ecological assessments.

The goal of this study was to determine whether existing tools used to evaluate ecological health are affected by diel variations of demersal fish community structure in Southern California coastal waters –

specifically, in a sandy habitat near two POTW ocean dischargers, by analyzing 24-hour trawl fish community data collected between 1979 and 1990.

2. MATERIALS AND METHODS

2.1. Sampling Design

Demersal fishes were sampled from 1979 to 1990 using an otter trawl to sample six soft-bottom habitat stations located on the Long Beach Shelf off Huntington Beach, California. The study area is in close proximity to two ocean outfalls through which highly treated and disinfected effluent is discharged offshore at 60 m depth. The outfalls are owned and operated by the Los Angeles County Sanitation Districts (LACSD) and Orange County Sanitation District (OC San), respectively (Figure 1). Each of these two public agencies have conducted extensive ocean monitoring programs, including trawl monitoring studies, for several decades.

Each trawl station sampled over the course of this study represented a different depth ranging from 6-100 m. The small otter trawl net used for sampling had a 3.8 m headrope, body of 1 cm mesh size and 4.1 m wings of 2.0 cm mesh, a 2.6 m cod end of 0.8 cm mesh in the liner and 0.3 x 0.5 m doors (Figure 2). Samples were collected during March (Spring), June (Summer), September (Fall) and December (Winter), with all four quarters being sampled during two years in the 11-year time frame (Table 1).

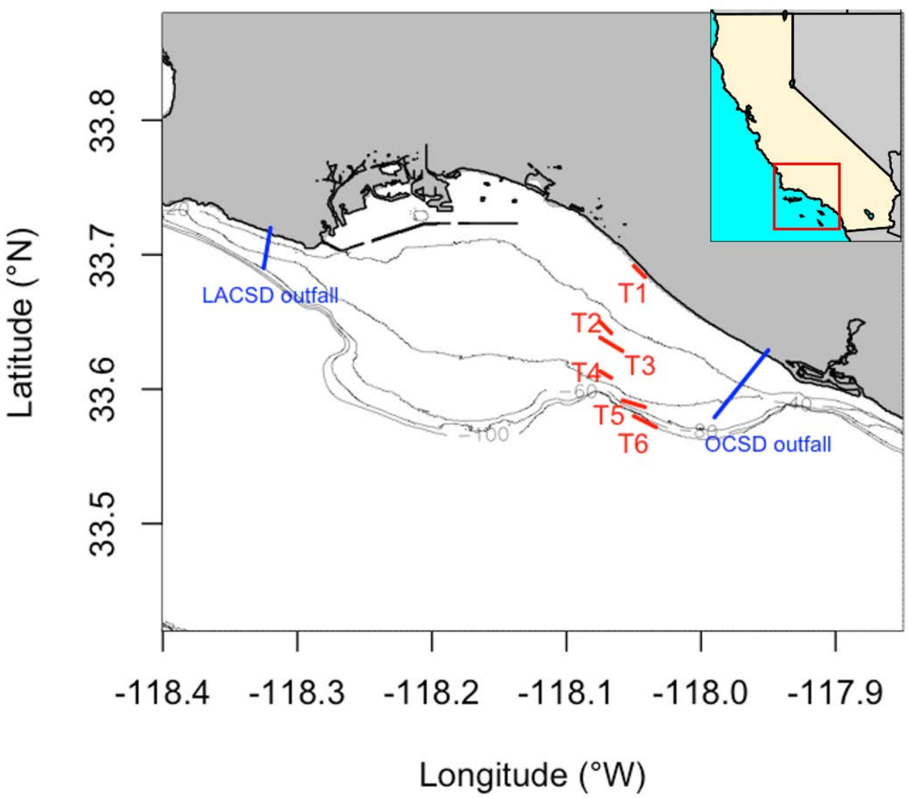

Figure 1. Map of trawl stations on the San Pedro Shelf where monitoring was conducted along 6 transects (T1-T6) from 6 – 100 m depth. Station transects are labelled in red. Gray isobaths lines are located at 20 m depth intervals. The Los Angeles County Sanitation Districts' (LACSD) and Orange County Sanitation District's (OCSD) outfall pipelines are pictured as blue lines to provide context to the proximity of the long-term trawl monitoring programs that occur in the same subregion as this study.

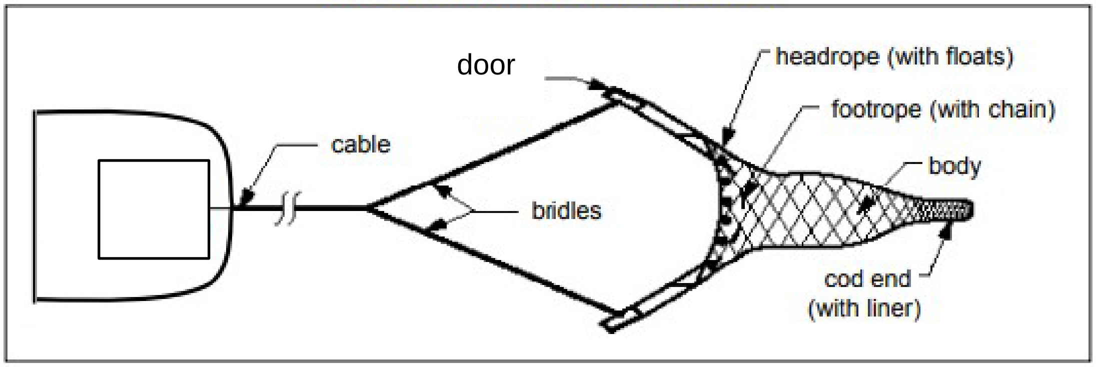

Figure 2. Diagram of semi-balloon otter trawl, adapted from Mearns et al., 1978.

Table 1. Trawl Sample Collection Dates

	Years								
	1979	**1980**	**1981**	**1982**	**1983**	**1987**	**1988**	**1989**	**1990**
March		X		X	X		X		X
June	X	X		X	X			X	
September	X	X	X	X	X				
December	X	X			X	X	X		

X = Six stations sampled, each with two replicates collected during the four 6-hour intervals within each 24-hour period.

For each 24-hour sampling period, six stations ranging in depth from six to 100 m (Figure 1) and paired replicate samples were collected. The Time of Day (TOD) was binned into four 6-hour sampling periods over the course of the day (Table 2); AM/Light (06:00-12:00), AM/Dark (12:00-06:00), PM/Light (12:00-18:00) and PM/Dark (18:00-24:00).

A total of 48 trawls, each of 5-minute duration, occurred during each 24-hour survey. The 5-minute trawl duration is comparable to that of most long-term monitoring programs in the SCB, including the Southern California Bight regional surveys which use both 5-minute and 10-minute trawl durations depending on the depth of the trawl (Walther et al., 2017). Two replicate trawls were taken at each of the six stations during each of four 6-hour intervals of a 24-hour period. The 20 sampling dates, with 48 trawls taken during each date, resulted in a total of 960 trawl samples.

In the field, fish were identified to species level, counted, weighed, and total length measured to the nearest mm. All identifications were standardized taxonomically, then prior to analysis, the names were harmonized with current nomenclature (Page et al., 2013).

Environmental variables recorded during each station visit included trawl depth, a temperature profile from the surface to near bottom (by bathythermograph) for each pair of trawls (except for 1979, and surface temperature-only for 1980, 1981, 1987, 1989, and 1990), and the time of day (TOD). Benthic grab samples were taken at each transect for sediment grain size analysis.

Table 2. 24-hour Diel Trawl Sample Design. Each "1" in the matrix represents one trawl sample taken.

Station		T1		T2		T3		T4		T5		T6	
Depth (m)		6		21		28		35		49		100	
Depth Zone		Inner Shelf		Inner Shelf		Inner Shelf		Middle Shelf		Middle Shelf		Middle Shelf	
Replicates		Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
Time of Day													
I PM Light	Noon to Dusk 1200-1800	1	1	1	1	1	1	1	1	1	1	1	1
II PM Dark	Dusk to Midnight 1800-2400	1	1	1	1	1	1	1	1	1	1	1	1
III Midnight to Dawn	AM Dark 0000-0600	1	1	1	1	1	1	1	1	1	1	1	1
IV Dawn to Noon	AM Light 0600-1200	1	1	1	1	1	1	1	1	1	1	1	1
Count of Trawls per Station / Day		8		8		8		8		8		8	
Total Count of Trawls / Day													48

2.2. Data Analyses

For abundance comparisons, the total fish catch for each of the two replicate samples was pooled together. Aggregating the replicate data allowed for reduced sampling variability and allowed comparability to local and regional trawl monitoring studies which use both 5-minute and 10-minute trawl durations. For the SCB regional trawl surveys, the abundances for the 5-minute trawls are doubled for comparison to the 10-minute trawls (Walther et al., 2017). By aggregating the two replicate samples together, this study used the same method of computing trawl metrics as has been used for the SCB regional trawl surveys.

To assess any effect of TOD on catch abundance, relative abundance was calculated as:

$$Relative\ Abundance = \frac{Count\ of\ all\ fish\ at\ Station\ X\ during\ time\ period\ Y}{\sum_{n=1}^{\infty}(Total\ count\ of\ all\ fish\ at\ Station\ X\ across\ all\ TOD\ )}$$

In addition to comparing abundance per catch, several well-known community metrics were also calculated:

- The Shannon Diversity index (Shannon, 1948) is commonly used to characterize species diversity in a community and accounts for both abundance and evenness of the species present.

- Species richness was calculated as the number of different species in each sample. Similarly, Margalef's index (Margalef, 1958) was used as another measure of species richness.

- The Pielou index (Pielou, 1969) was used to compare equitability or evenness of species diversity between samples.

- The Brillouin index (Pielou, 1966) was used to measure the diversity of the population as a whole. Pielou (1966) recommends use of the Brillouin index in all situations sampling was non-random, as was the case for this study.

To gauge the condition of the fish communities relative to potential pollution impacts, a demersal fish biointegrity index, the Fish Response Index (FRI; Allen et al., 2001) was calculated. The FRI is a multivariate index that provides the abundance-weighted average pollution tolerance score of all the fish species in a sample. The FRI was designed to recognize that diverse fish communities are expected to occur at different depths and regions of the Southern California Bight (SCB). The FRI controls for this natural variability by utilizing a pollutant tolerance index to determine whether observed populations are predominantly represented by pollution-tolerant (an indication of possible impact) or pollution-intolerant species. The pollution tolerances of the species were determined from ordination analysis of a large multi-year data set composed of trawl fish survey results across a range of shelf and slope depths, habitats, and sediment pollutant levels within the SCB. The FRI was calibrated and validated using almost 30 years of data around wastewater outfalls in depths between 20 and 215 m, and correlated with a well-documented pollution gradient (Allen et al., 2001). This approach is similar to that used in the Benthic Response Index (BRI; Smith et al., 2001) to assess infaunal community condition in the SCB (Bergen et al., 2001). The reference condition threshold value of 45 was computed for the FRI as the 90% tolerance interval bound for observations from areas where the BRI was in reference condition. The FRI was developed for three depth zones; inner shelf (9-40 m), middle shelf (30-120 m), and outer shelf (100-215 m). An FRI score at or below 45 indicates that the fish community is in reference condition.

Statistical comparisons of univariate measures were made via notched box plots which depict the distribution and variability of values in each box. The notched boxplots consist of a “box” which depicts the relative abundance of the middle 50% of the data. The horizontal line across the box is the median value of each grouping, and the whiskers above and below the boxes are 1.5 times the range of the boxes. Anything that falls outside the whiskers is considered a potential data outlier. The notched boxplot allows evaluation of 95% confidence intervals for the medians of each boxplot. When the notches within the boxplots do not overlap with one another, one can conclude with 95% confidence that their medians differ.

Multivariate statistical analyses were conducted using vegan (Oksanen et al., 2017). A log(x+1) transformation was performed on the invertebrate and fish abundance datasets, resulting in a data matrix for each dataset which decreased the influence of prevalent species and increased the weight of rare species. A Bray-Curtis similarity matrix was created from transformed data. Input data were the abundances of taxa occurring in the trawl surveys. To better understand variability in assemblage structure and relative importance of Time of Day (TOD), several labels were applied to the dataset including four TOD factors, six depth factors, and shelf zone (Inner Shelf and Mid-shelf). An ordination was then constructed, and non-metric multidimensional scaling (nMDS) was used to visualize the effect of factors such as TOD and depth.

3. RESULTS

3.1. Sea Surface Temperature

Ocean temperature values were between 13 and 23ºC at the surface (SST), and between 6 and 21ºC at the bottom (NBT; Figure 3). The trawl surveys that occurred over the course of the study period represented various oceanic periods: El Niño, a regime causing relatively warm water temperatures, La Niña, a cold-water regime, and neutral periods which were neither warm nor cool (Figure 3). There was no clear relationship between SST and the number of individual fish caught at those temperatures (as relative abundance, Fig. 4).

3.2. Relative Abundance

Time of day (TOD) had a marked effect on abundance of fish caught in the trawls (Figure 5). Samples taken during the evening and early morning (ostensibly during dark /nighttime hours) had higher abundances of fish than samples taken during the daytime. Lowest relative abundance of catches was found during the morning daylight period (06:00 – 12:00), and highest relative catches were collected during the evening trawls (18:00 – 24:00) which was a period predominantly without daylight. Overall, the fish abundance patterns for TOD held regardless of sampling date /season (Figure 6).

The effect of TOD on fish catch was even more marked when the data were isolated by depth (station). At the shallowest (6 m) and deepest station (100 m), TOD had little impact on catch, however, at intermediate depths (stations 2-5 at depths 21 – 60 m) there was a larger effect of TOD on fish catch (Figure 7).

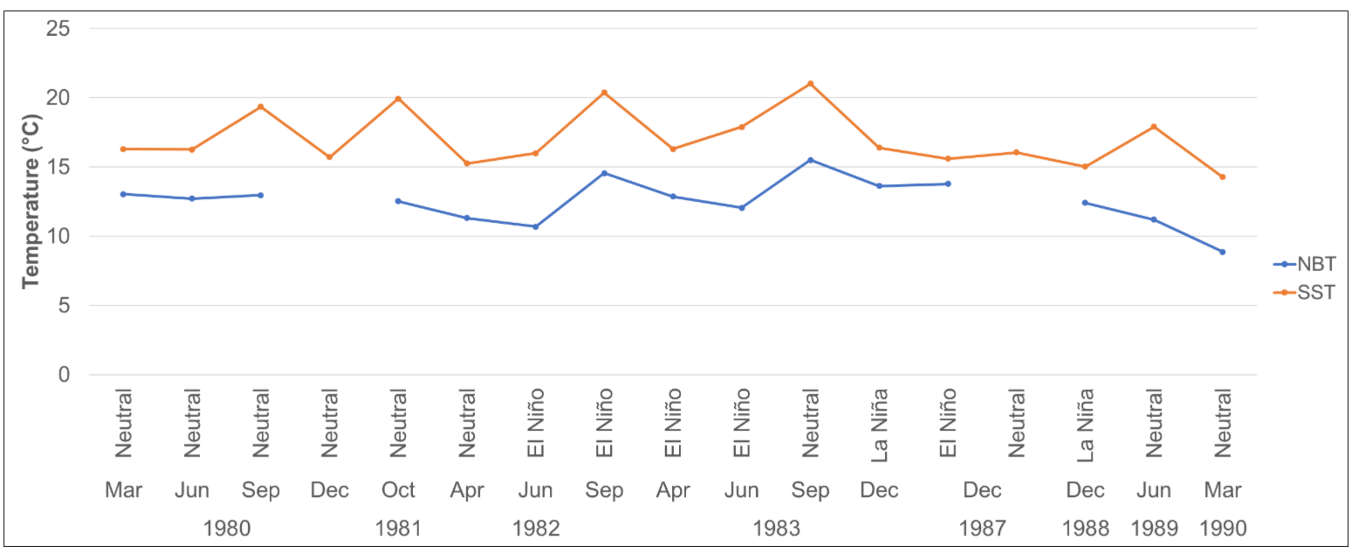

Figure 3. Average sea surface temperature (SST) and near-bottom temperature (NBT) measurements taken during the trawl surveys. Episodic warm (El Niño), cool (La Niña), and Neutral periods are indicated for each year as measured by the Oceanic Niño Index (ONI).

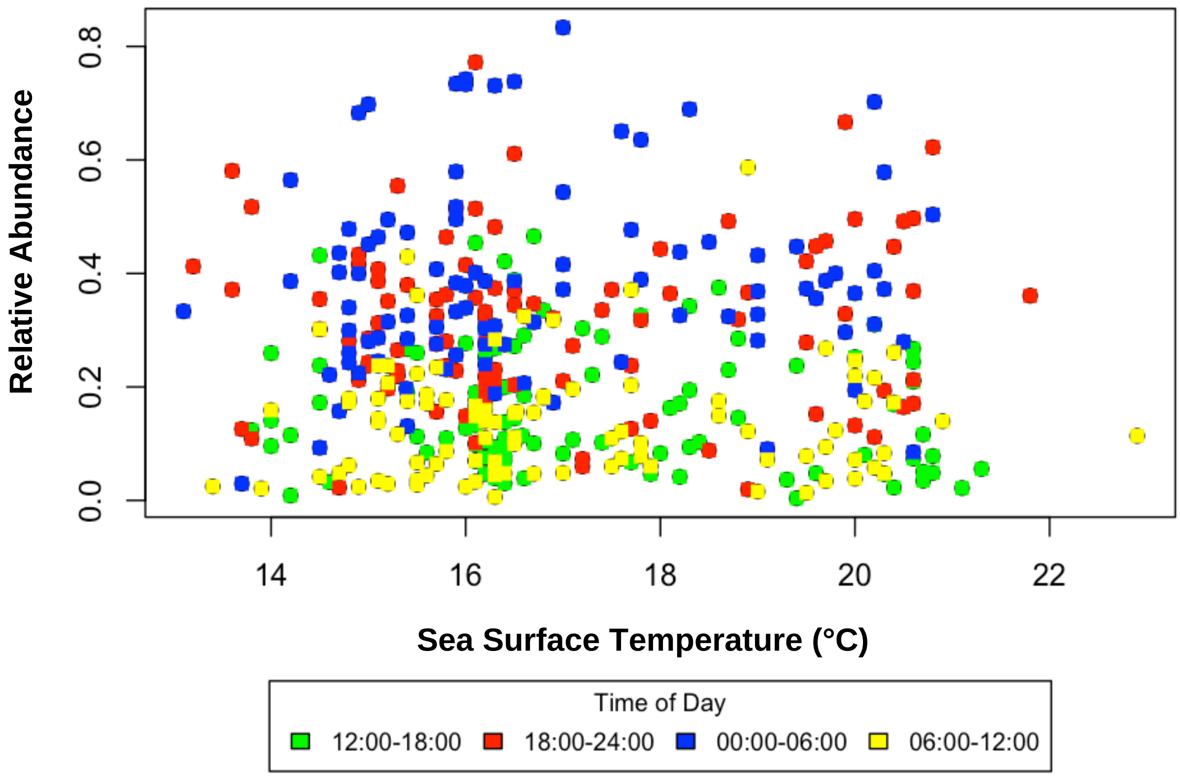

Figure 4. Relative abundance of all samples plotted by Sea Surface Temperature (SST) and Time of Day (TOD). Relative abundance is scaled from 0 to 1.

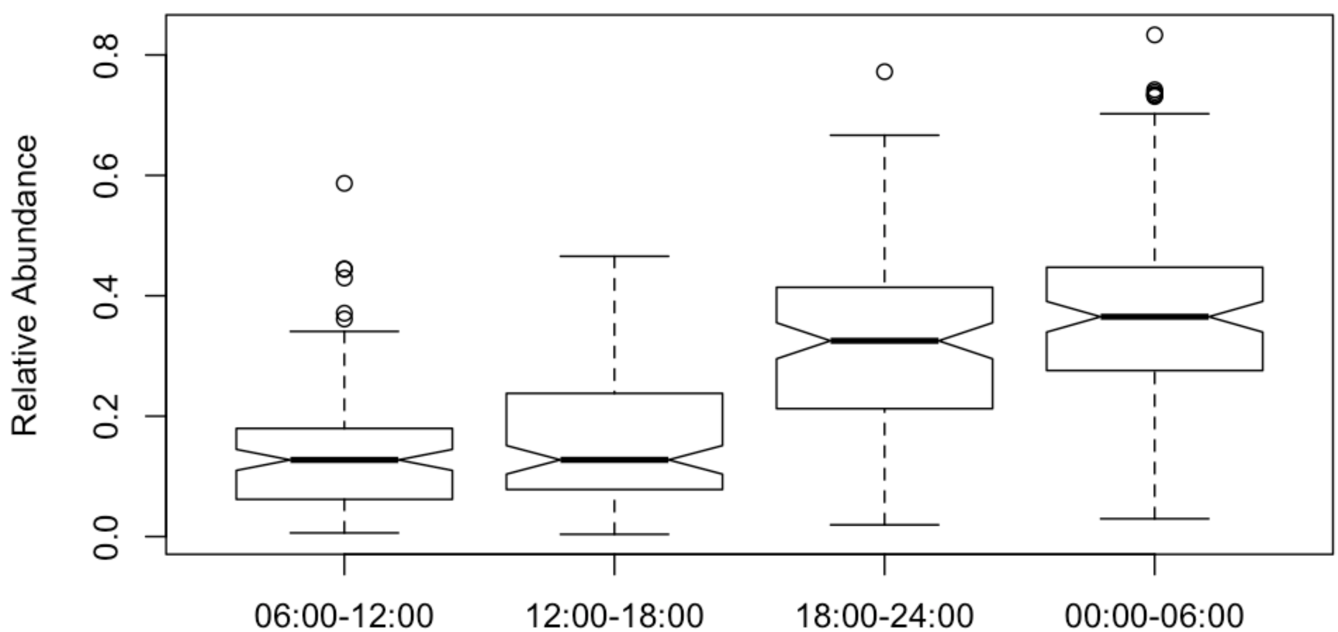

Figure 5. Total relative abundance of fish by time of day (TOD) across all stations. Relative abundance for each sample was calculated as the total abundance of fish within that sample, divided by the total number of fish caught during the entire 24 h period at that station, and ranges from 0 (least abundance) to 1 (highest abundance). These boxplots depict the distribution and variability of relative abundance values at each station

and TOD. The notched boxplots consist of a “box” which depicts the relative abundance of the middle 50% of the data. The horizontal line across the box is the median value of each grouping, and the whiskers above and below the boxes are 1.5 times the range of the boxes. The notched boxplot allows evaluation of 95% confidence intervals for the medians of each boxplot. When the notches within the boxplots do not overlap with one another, one can conclude with 95% confidence that their medians differ.

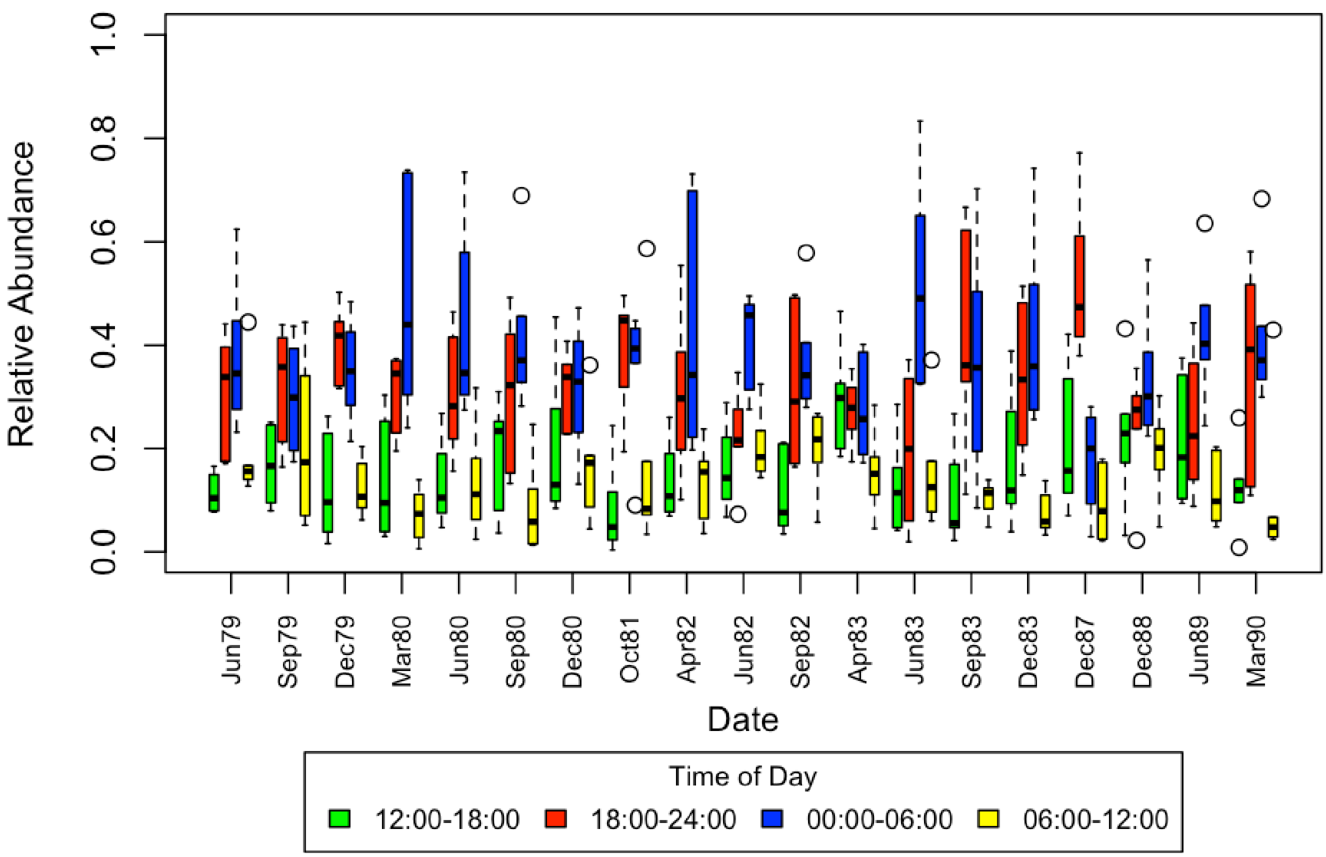

Figure 6. Relative abundance of fish by Sampling date (Date) and Time of Day.

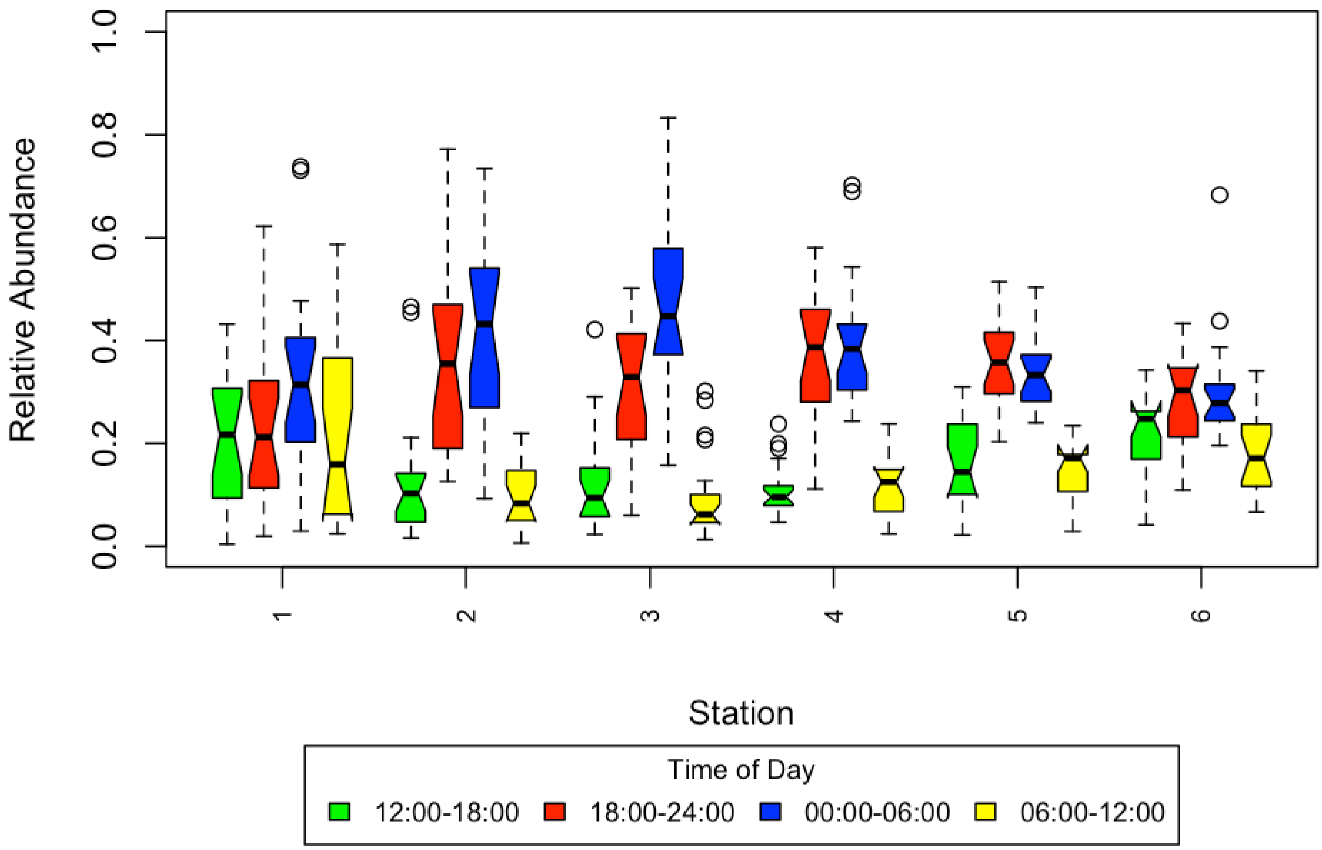

Figure 7. Relative abundance by Time of Day for each station, ranging in depth from 6 – 100 m. (Depths: Transect 1= 6 m; Transect 2 = 21 m; Transect 3 = 28 m; Transect 4 = 35 m; Transect 5 = 49 m; Transect 6 = 100 m). These boxplots depict the distribution and variability of relative abundance values at each station and TOD. The notched boxplots consist of a "box" which depicts the relative abundance of the middle 50% of the data. The horizontal line across the box is the median value of each grouping, and the whiskers above and below the boxes are 1.5 times the range of the boxes. The notched boxplot allows evaluation of 95% confidence intervals for the medians of each boxplot. When the notches within the boxplots do not overlap with one another, one can conclude with 95% confidence that their medians differ.

3.3. Community Composition

There was a marked difference in species richness and diversity (Figures 8 - 11) between daytime and nighttime sampling across all sample dates and depths with the highest values occurring in the evening (18:00-24:00) and from midnight to pre-dawn (00:00 – 06:00). Unlike the species richness and diversity indices, evenness did not vary widely when compared against TOD (Figure 12).

The average Fish Response Index (FRI) score for all samples was 28.9, well under the threshold for reference condition which is ≤ 45, which is a good indication that most areas sampled were in reference condition, i.e., unimpacted by chemical sediment contaminants at the time of collection. There was no difference in overall FRI scores when compared to TOD (Figure 13), but when the scores were also compared against station (Figure 14), elevated scores were detected during dark/ nighttime collection periods from 6 pm to midnight (18:00-24:00) and midnight to 6 am (00:00 – 06:00), primarily at stations 2, 3, and 4. FRI scores at station 4 were elevated beyond reference condition during both nighttime sampling periods.

NMDS ordination of trawl fish assemblages at the six stations on the San Pedro Shelf (Figure 15) indicated the occurrence of strongly-grouped fish assemblages which varied mostly by depth, then by TOD.

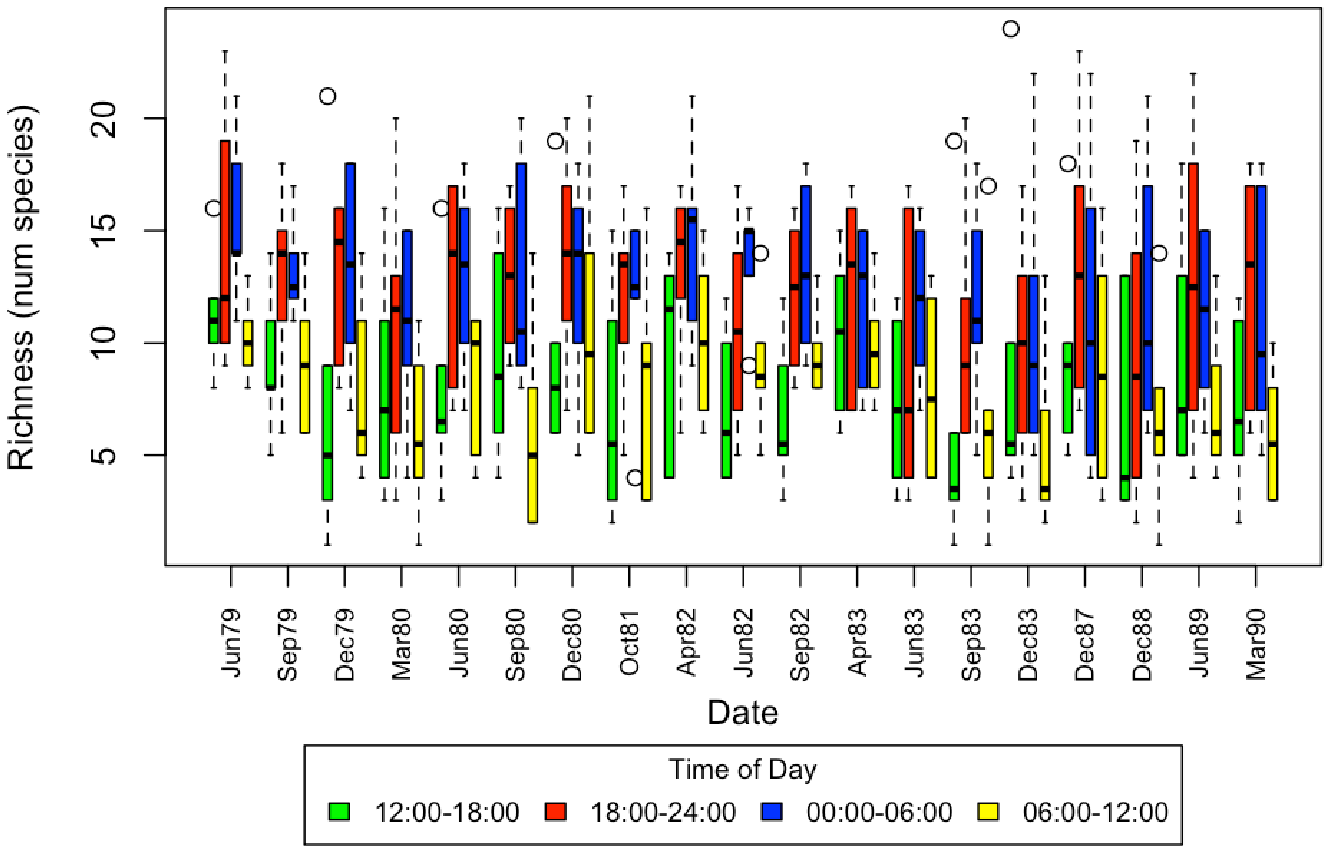

Figure 8. Species richness (the number of species present in a sample) by Sampling date (Date) and Time of Day.

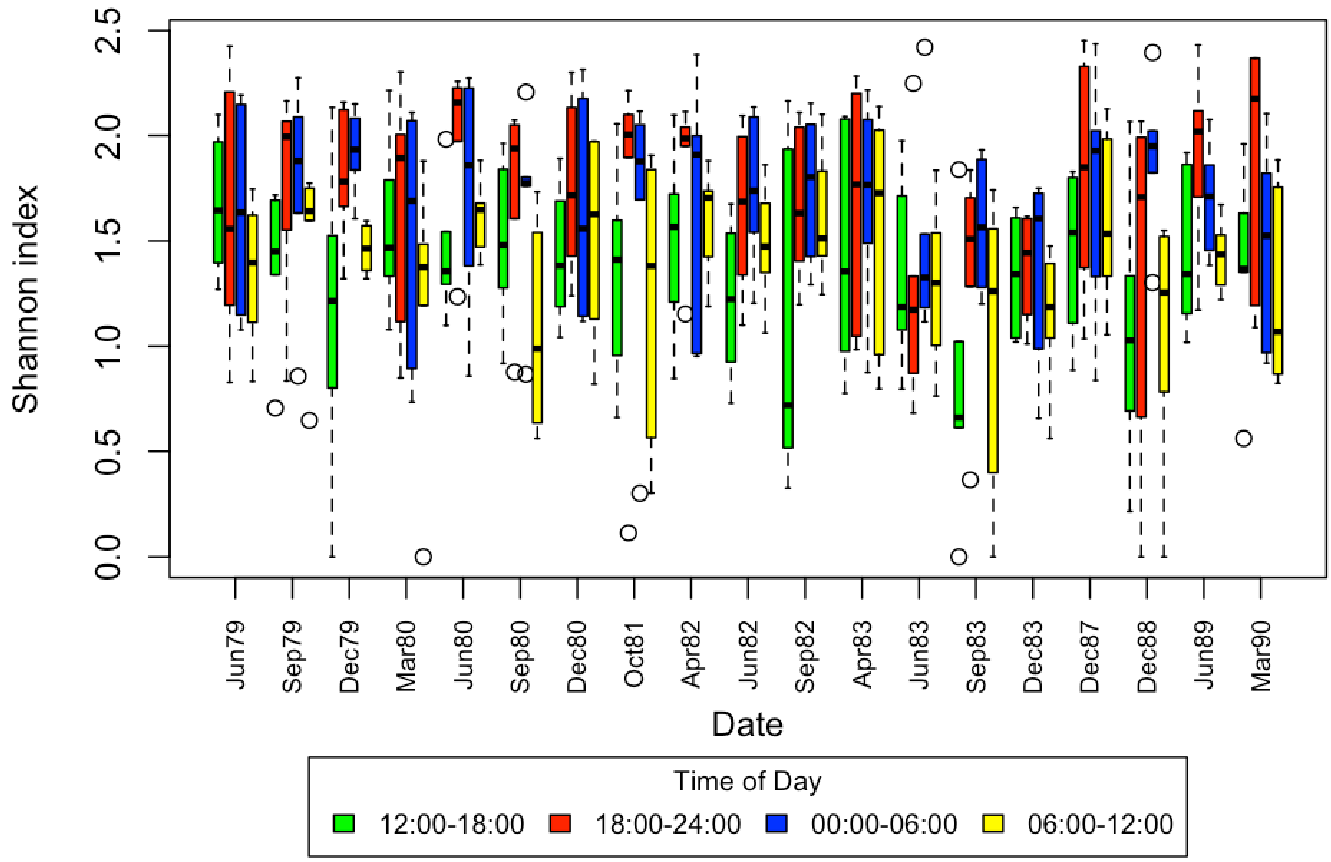

Figure 9. Shannon Diversity Index by Sampling date (Date) and Time of Day.

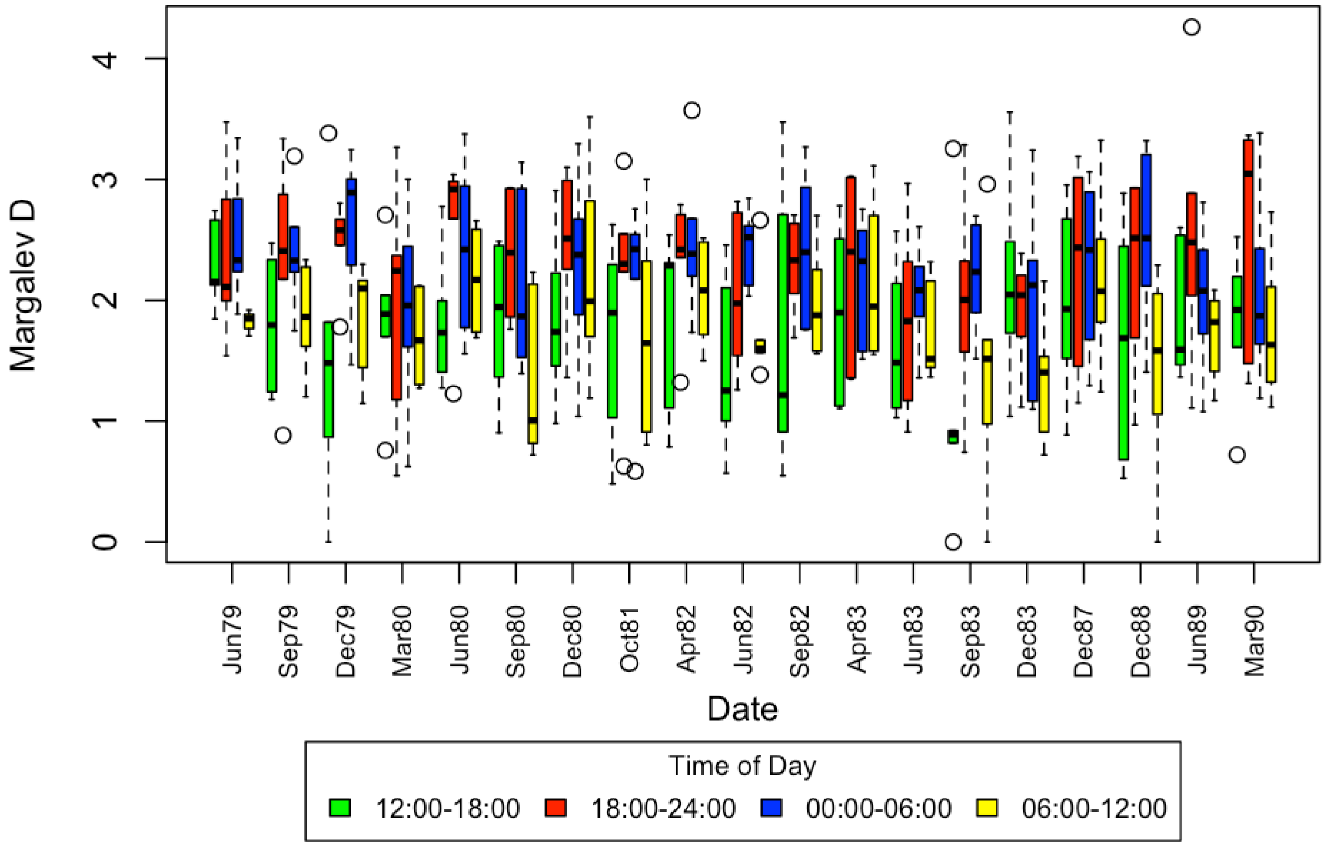

Figure 10. Margalef's richness index by Sampling date (Date) and Time of Day.

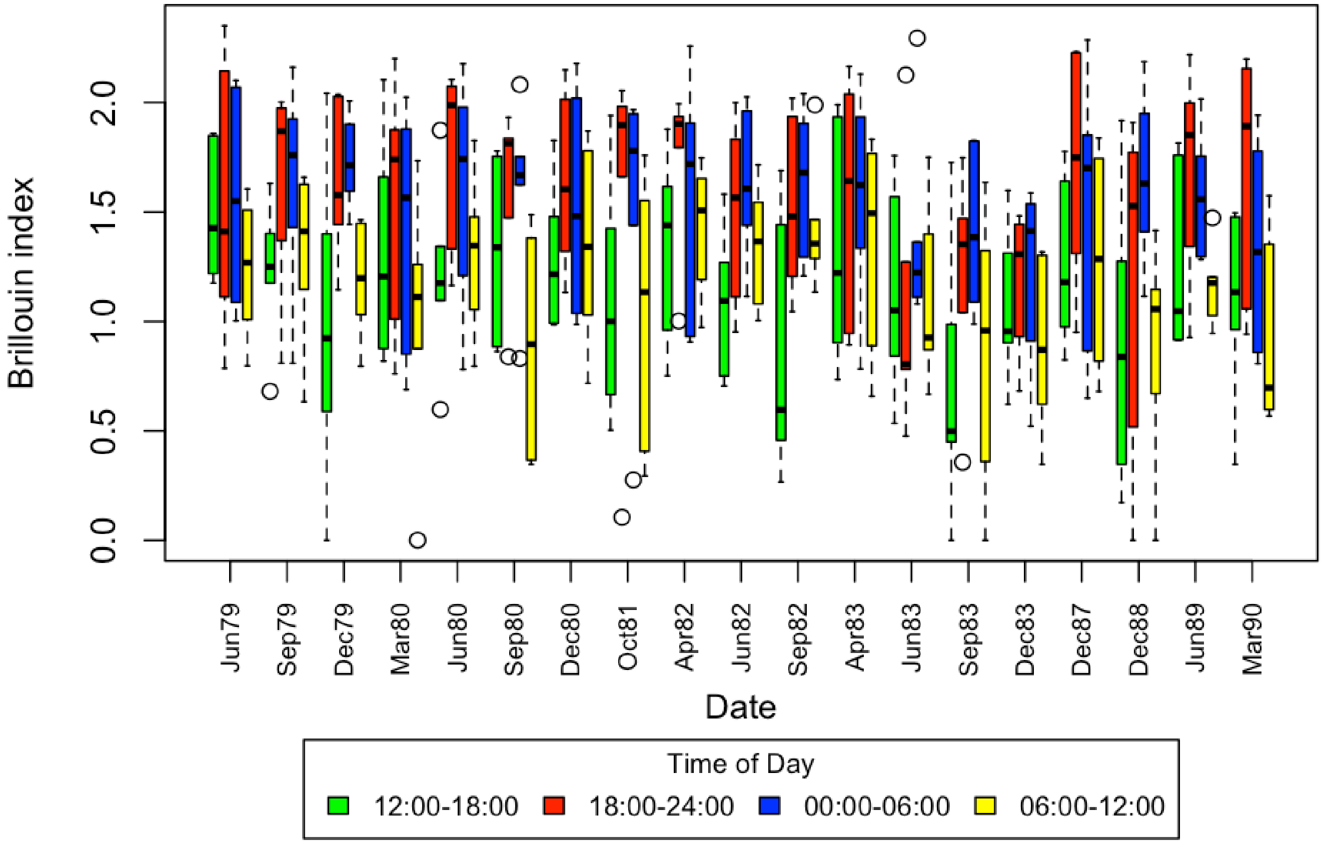

Fig. 11. Brillouin index by Sampling date (Date) and Time of Day.

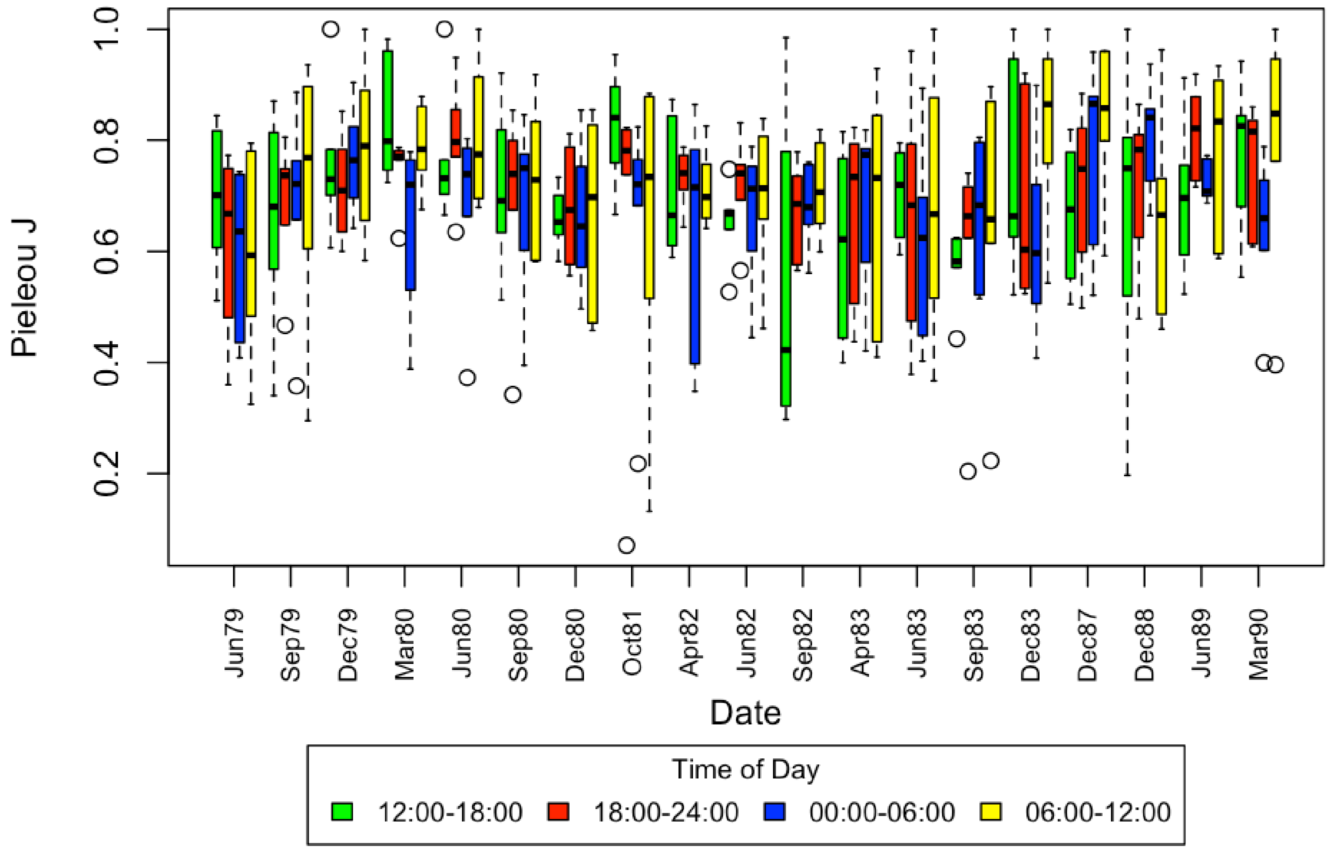

Figure 12. Pielou's Evenness index (J) by Sampling date (Date) and Time of Day.

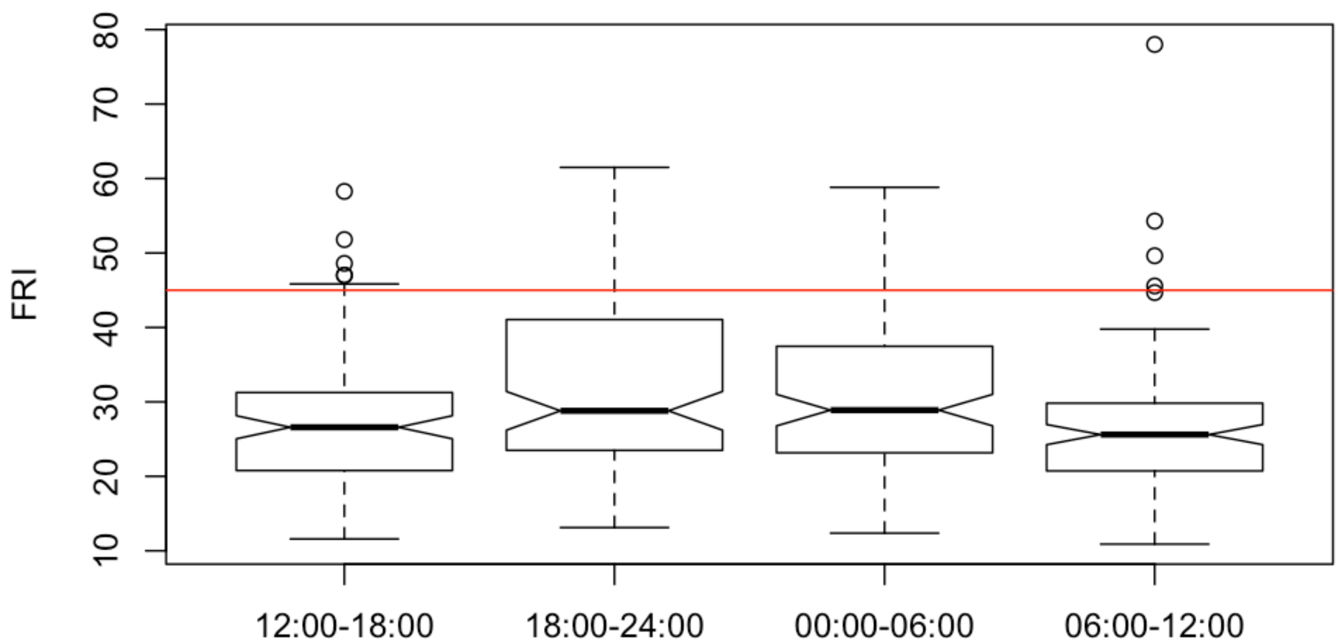

Figure 13. Fish Response Index (FRI) by Time of Day (TOD). FRI values < 45 indicate reference condition. These notched box plots depict the distribution and variability of FRI values for each TOD. The notched boxplots consist of a "box" which depicts the relative abundance of the middle 50% of the

data. The horizontal line across the box is the median value of each grouping, and the whiskers above and below the boxes are 1.5 times the range of the boxes. The notched boxplot allows evaluation of 95% confidence intervals for the medians of each boxplot. When the notches within the boxplots do not overlap with one another, one can conclude with 95% confidence that their medians differ.

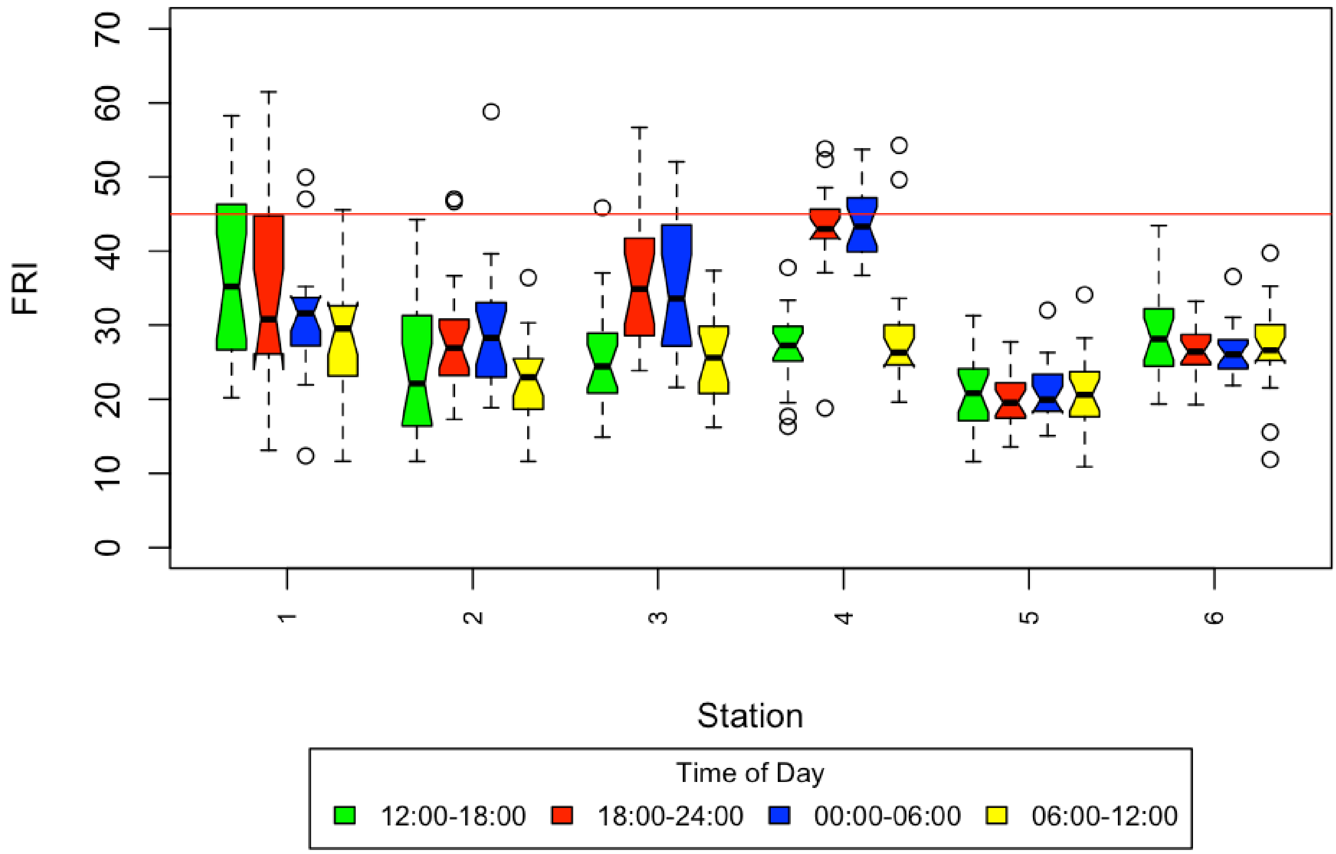

Figure 14. Fish Response Index (FRI) by Station and Time of Day. FRI values < 45 indicate stations in reference condition. These notched box plots depict the distribution and variability of FRI values for each TOD. The notched boxplots consist of a “box” which depicts the relative abundance of the middle 50% of the data. The horizontal line across the box is the median value of each grouping, and the whiskers above and below the boxes are 1.5 times the range of the boxes. The notched boxplot allows evaluation of 95% confidence intervals for the medians of each boxplot. When the notches within the boxplots do not overlap with one another, one can conclude with 95% confidence that their medians differ.

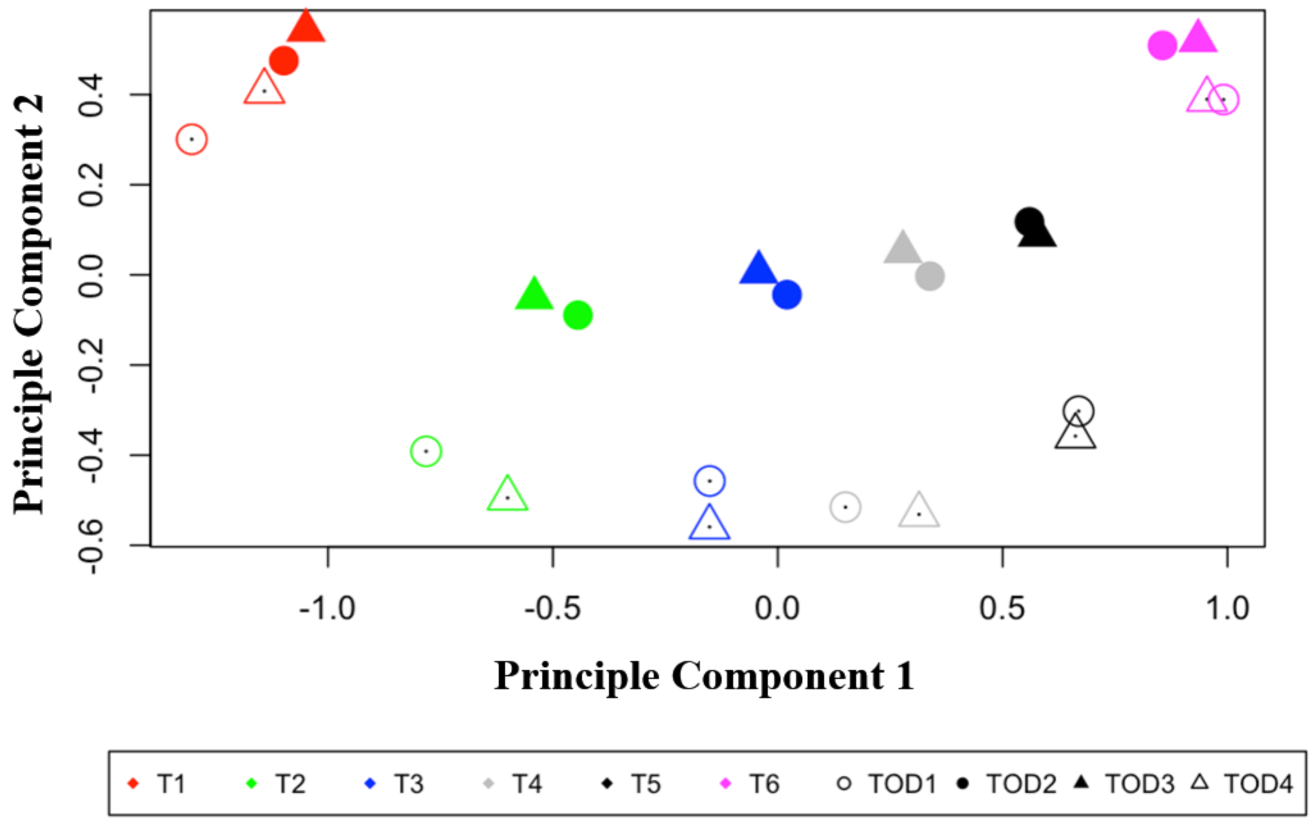

Figure 15. Non-metric multidimensional scaling (nMDS) plot of Bray-Curtis similarities based on log(x+1) transformed fish community sample data. Points closer to one another in ordination space are more similar than those apart. The six stations on the San Pedro Shelf are indicated with different symbol colors and shapes. Time of Day (TOD) with filled shapes are during night without light, and unfilled shapes are TOD during daylight hours. Principle Components represent the driving forces behind the assemblage structure, e.g. depth vs TOD. Biological data include all stations, seasons, and years.

3.5 Population Variability

As seen in the nMDS community analysis, each station, which was analogous to sampling depth, was characterized by different assemblages of fish species. The most notable differences were between stations T1 (6 m), which was typified by White Croaker and Queenfish, and station T6 (100 m), which was characterized by Pacific Sanddab, Plainfin Midshipman, California Tonguefish, Yellowchin Sculpin, and Dover Sole (Figure 16).

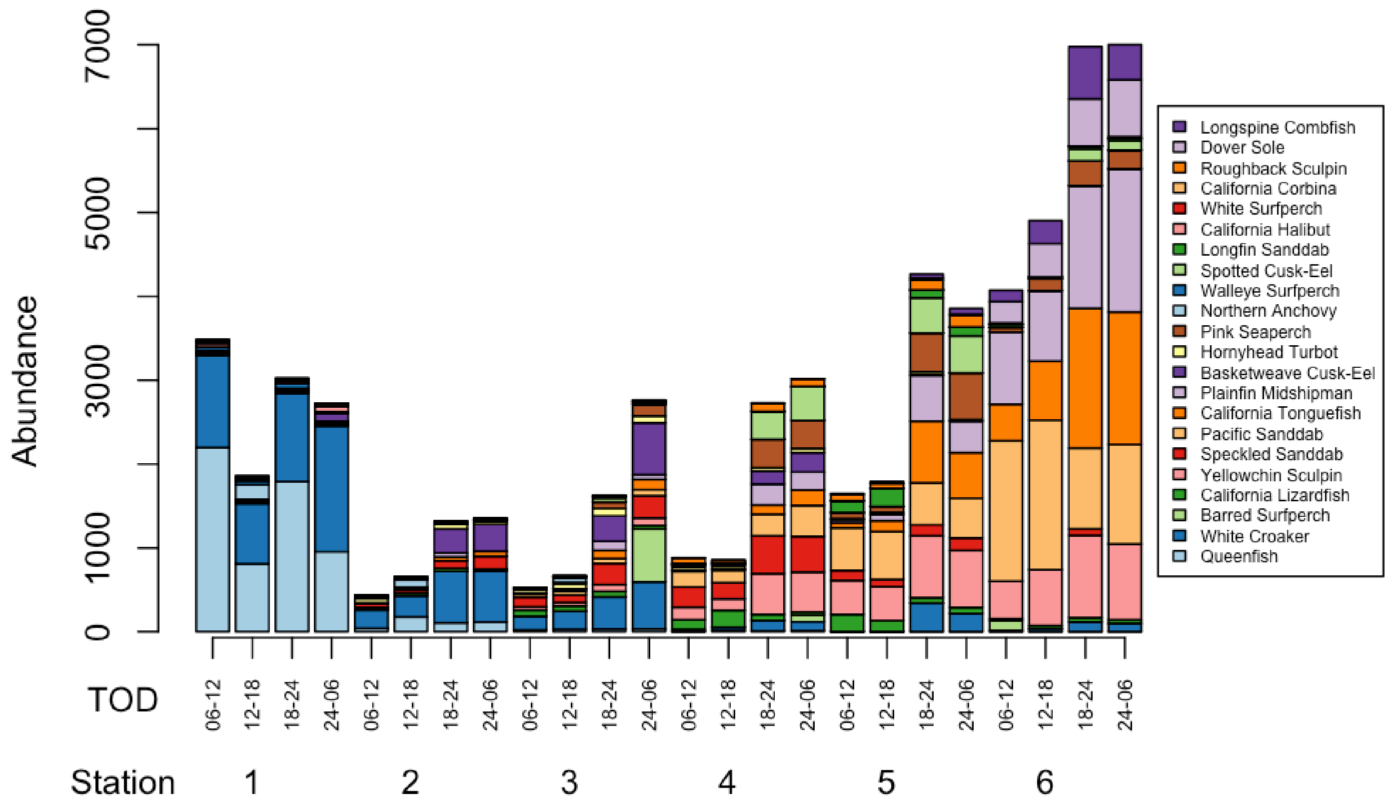

Figure 16. Abundance of the top five most abundant species for each time of day (TOD) and station.

4. DISCUSSION

For all stations, abundances were higher during nighttime hauls. If all species were equally available to the trawl during both day and night, then the most reasonable explanation for greater abundances of many species at night might be gear avoidance (i.e., actively swimming away from the trawl net opening) during daylight hours, but this was not the case. First, many species that were more abundant at night are known to have behaviors which make them less available to the trawl during daytime (e.g., daytime burrowing or movement out of the open-bottom demersal habitats swept by the trawl). One result of these daytime behaviors could be increasing fish density during the day in habitats with hard substrates such as natural and artificial reefs that are not sampled by trawl gear (e.g., Williams et al., 2010).

Spatial and temporal trends in diversity and assemblage structure are not surprising given the overall abundances of various species in the study area. Higher diversity at night was obviously linked to the large number of species that were more abundant during that time period.

The median biointegrity of each station was in reference condition as measured by the FRI. These conditions were similar to those across the SCB where most trawl-caught fish communities have been in reference condition since 1994 (Walther et al., 2017). On the nearby Palos Verdes shelf, FRI scores have been in reference condition since the early 1980’s (LACSD 2020). On the inner shelf (≤30 m), TOD had an effect on FRI scores, indicating diel migration of pollution-tolerant fish communities to the affected areas from 6 pm to 6 am.

Diel, regional, and depth differences were prominent in terms of assemblage structure, with depth being the largest driver of community differences. The results support the idea that in addition to factors such as region, depth, season, etc., ecosystem-level models of shelf ecosystems should consider diel period. Existing ecosystem models are capable of explicitly accounting for spatial variability (e.g., Chagaris et al., 2015; Grüss et al., 2015), but this is not generally the case for time of day. This study, which focused primarily on smaller-bodied fishes that largely form the prey base for larger fish species, indicated that for the vast majority of species, abundances were markedly higher at night. Accordingly, models constructed based on results of sampling only during daylight hours may yield an incomplete and misleading picture of conditions in these habitats. This may have important implications to modeling efforts that largely rely on reported co-occurrence in defining potential trophic interactions. Further research on how these patterns may influence ecosystem structure and function, especially in terms of potential outputs and subsequent management actions, is warranted.

Monitoring coastal ecological conditions and giving context to ongoing long-term local and regional monitoring programs provides a better understanding of drivers behind variations in fish community condition and structure. Finally, this study enables broad dissemination of valuable information on demersal fish communities that might otherwise remain unpublished.

LITERATURE CITED

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