Herbivorous No More: Tidal Migration in the Midst of Fishery Discards Shock the Trophic Web in Subtropical Intertidal Communities

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ABSTRACT

Fishery discards are a prevalent practice that impacts intertidal zones by introducing a new food source. The aim of this study was to determine how the presence of fishery discards impacts the abundance and richness of fish species with a particular focus on the variations between high and low tide. The study was carried out by utilizing baited remote underwater video survey systems (BRUVs) to record fish species interacting with the bait. Subsequently, the video footage underwent a frame-by-frame analysis, and data was collected in terms of which species were present, the tide during which they were observed, the maximum number of that species in a frame, their typical feeding habits, and whether they fed on the discards. The collected data was organized into tables and multiple figures, revealing a distinct separation between low and high tide conditions concerning the abundance of various species. These findings help to underscore the significant impact of tides on the distribution of species abundance in the presence of fishery discards, as well as the influence of these discards on the feeding behaviors of specific species. Future regulations on fishery discards should continue research using BRUVs to determine how they will impact ecosystems and trophic levels.

KEYWORDS

Fishery Discards, BRUVS, Max Number N, Species abundance, Species richness, Moreton Bay, Tidal migration, Scavengers, Herbivores

INTRODUCTION

The practice of fishery discards can be defined as the part of the total organic material in a given catch that is thrown back to sea and made up of dead catch (Van Putten *et al.* 2020). It has been estimated that worldwide, approximately 8% of total catch is discarded with certain fisheries having higher and lower percentages (Kelleher *et al.* 2005). For the majority of fisheries that fish for multiple species, the unintended capture of marine organisms that will not be used is almost always inevitable (Suuronen *et al.* 2020). Fishery discards result in irreversible impacts that affect the function and diversity of the ecosystems into which they are thrown, and predicting these specific effects is very challenging. (Bellido *et al.* 2011). Discard practices tend to vary among different fisheries across the world, but a common issue with fishery discards is that a large proportion of this material ends up sinking to the benthos, becoming bioavailable to benthic scavengers and communities (Ramsay *et al.* 1997). Another layer of this problem lies in the fact that many fishery discards are released into different ecosystems than they came from, primarily due to the impacts of fishing practices like bottom trawling (Jennings and Kaiser 1998). When trawling occurs, the gear used disturbs benthic sediment and organisms as it is pulled along the sea floor by fishing vessels and simultaneously upsets the structure of these communities by moving species to different levels of the ocean and to different ocean ecosystems (Bellido *et al.* 2011, Jennings and Kaiser 1998, Van Denderen *et al.* 2019).

This increase in food resources from different parts of the ocean results in major consequences that alter the dynamics of the ecosystem (King *et al.* 2007, Bellido *et al.* 2011). The primary fate of the discards is to be food sources for organisms including scavenging seabirds, fish, and marine benthic scavengers, which has been demonstrated to positively impact their populations (King *et al.* 2007). This relationship results in trophic cascades because the sea birds encounter the discards first and are typically selective in what they consume (King *et al.* 2007). From that point, the remaining discards become available to fish and, in turn,to marine benthic scavengers (Heath *et al.* 2014, King *et al.* 2007). Once the discards have trickled down through the trophic web, the remainders decompose and the nutrients can be reintroduced back into the system by means of primary production (Heath *et al.* 2014). This example illustrates how scavenger species tend to specifically benefit because discards fall within their natural food sources (Depestele *et al.* 2018, Schlacher *et al.* 2013). Marine scavengers are characterized by their ability to detect and be attracted to carrion, thus it can be expected that their species richness will be high in the presence of fishery discards (King *et al.* 2007, Schlacher *et al.* 2013). This specific behavior makes the use of bait in research an efficient method to study marine scavenger species abundance and richness (King *et al.* 2007).

Fishery discards are a common practice in Moreton Bay on North Stradbroke Island, and the following research study examined how it affects marine species richness and abundance. The study relied on the use of baited remote underwater video survey systems (BRUVS), which employed cameras attached to bait to document species that enter the frame (Harvey *et al.* 2021). The utilization of the BRUVS technique in research offers numerous advantages. (Cappo *et al.* 2007). BRUVS are non-extractive and therefore do not cause observable disturbances to the benthos and associated substrate (Cappo *et al.* 2007). For this reason, they can be employed in marine reserves to collect information on species abundance and richness. In addition, every organism that enters the field of view due to the presence of bait will be recorded. These reasons make the BRUV experiment replicable and allow research to avoid false negatives (Cappo *et al.* 2007). By employing baited experiments, this study examines the differences that are incurred by fishery discards at the moment they reach the benthos (Whitmarsh *et al.* 2016).

This study presents opportunities to uncover a glimpse into the question of how marine organisms are reliant on fishery discards and how this reliance ultimately alters ecosystems and trophic webs (Catchpole *et al.* 2005). For instance, the impact of fisheries can potentially lead to typically herbivorous marine organisms that mainly feed by grazing altering their habits to opportunistic feeding by scavenging on carrion (Depestele *et al.* 2018). Furthermore, the impact of fisheries can be studied in the context of tidal changes, as high and low tides have different effects on species abundance and richness. (Gibson 2003, Lee *et al.* 2014).

Tides exert a significant influence on coastal fish assemblages in shallow nearshore environments (Lee *et al.* 2014). High tide is associated with increasing water depths, which results in a higher abundance of predators observed because they are able to migrate with the incoming tide (Gibson 2003, Lee *et al.* 2014). During the low tide, predators migrate back to deeper waters, and smaller species increase in abundance and come out of hiding from predators (Gibson 2003). Low tides are also linked with abiotic stressors, including hypoxia, which prompts many fish species to migrate out (Martin 1995). Generally, low tide tends to reduce the abundance and species richness on reefs, whereas high tide increases both factors (Gibson 2003, Lee *et al.* 2014, Martin 1995). The objective of this study is to examine whether the tidal cycle, specifically focusing on high and low tide, alters fish species richness and abundance in response to the presence of fishery discards.

METHODS AND MATERIALS

For the purposes of this research study, the use of BRUVSs, which are defined as Baited Remote Underwater Video Survey systems, was implemented. The goal was to investigate how the presence of fishery discards affects marine species richness and abundance during high and low tides. The study was conducted at Harold Walker Jetty (HWJ) in Moreton Bay on North Stradbroke Island, with the following coordinates: latitude 27°30’13.97” S and longitude 153°24’5.95” E. This site was a designated general-use zone, which means it allows for a range of activities that include trawling (Van de Geer 2013).

The components of the BRUVS were modeled based on the summary of BRUVS’s designed in an Australian-wide synthesis of BRUV data (Harvey *et al.* 2021). The system consisted of a cinder block attached to a two-foot-long PVC pipe with a plastic mesh bait bag on the opposite end of the pipe (Cappo *et al.* 2007, Whitmarsh *et al.* 2016). For the surveillance aspect of the BRUVS, a Go Pro Hero 9 was secured to the PVC in between the block and the bait bag, facing the bait bag. Three whole Australian pilchards (S. Sagrax) were used as the bait in each deployment and placed into the mesh bag before each drop. The bag was secured, compressed, and flattened to create an even plume dispersal, which is a common method for effectively distributing scent to attract organisms to our BRUV (Watson *et al.* 2009, Whitmarsh *et al.* 2017). The Go Pro was set to a wide lens and recordings were started directly before each deployment. There was a rope attached to the end of the cinder block that was utilized to gradually lower the entire rig into the water until it reached the bottom and was at a stable position. At this point, the rope was secured to the surface of the jetty. The length of the deployment time was set to be twenty minutes from the time the device settled on the ocean floor to when it was pulled back up. Research has shown that shorter deployment times are less likely to be biased in terms of estimates of species richness and abundance (Coghlan *et al.* 2017).

During the deployment time period, we recorded observations in our research booklet, documenting any relevant activities that occurred and had the potential to influence the outcome of the experiments. This included noting the arrivals and departures of passenger and vehicle ferries, as well as the presence of fishermen on the same dock where the BRUV was deployed. After each deployment when the BRUV was removed from the water, the depth of the water was marked and recorded with a tape measure. This study spanned three consecutive days, involving baited drops on each day. For the first two days, there was one drop at low tide and one drop at high tide. On the third day, there were two drops at high tide and two drops at low tide, with each pair of drops timed to occur thirty minutes before and after the peak tide. This allowed us to develop additional data without skewing the results (Jones *et al.* 2021).

Video Analysis

After the completion of the deployments, frame-by-frame video analysis was conducted to record data. Each 20-minute drop was analyzed beginning when the BRUV reached the bottom and finishing when the BRUV was lifted off of the ocean floor. We recorded the activity of species, noting which species entered the frame, how many passed through, whether they fed on bait and the time that they entered the frame (FishBase). This data was later used to analyze potential changes in the feeding behaviors of organisms. The Max N statistical method was applied to construct the data on marine species richness and abundance because it was the most common method used in BRUVs research (Harvey *et al.* 2021, Sherman *et al.* 2018, Whitmarsh *et al.* 2017). Max N stands for the maximum number of organisms in a specific species that was present in the camera's field of view in any one video frame for the duration of each 20-minute deployment (Cappo *et al.* 2007, Currey-Randall *et al.* 2020, Harvey *et al.* 2021, Whitmarsh *et al.* 2017). The time stamp was taken for each species max number N during all of the drops. In certain instances, a species only occurred once and thus was not statistically recorded. The utilization of this system made sure that the data did not double count organisms that left the frame and returned (Cappo *et al.* 2007, Currey-Randall *et al.* 2020).

Statistical Analysis

The species found were recorded and their abundance was listed for each individual drop. The data of the maximum number N for each species in the baited drops was compared for high tide and low tide drops. In order to parse through the data collected, we applied a Bray-Curtis dissimilarity matrix to rearrange the data to find similarities between the deployments. This was used to create a scatterplot to arrange the data and compare the differences at Harold Walker Jetty for high and low tides in terms of which tide species appeared in. Another scatterplot was created to look at fish species abundance for each drop.

For a more detailed analysis of abundance for each drop, we calculated the mean and standard deviation for each species in both low and high tide deployments. Then, the total number of fish per drop was averaged for low and high tide to find the estimated minimum fish abundance for each. We also looked at the differences in the total number of species found at the Harold Walker Jetty at high tide compared to the total number found at low tide using data from seven of the drops. This was completed by creating a bar graph for species richness.

RESULTS

<u>Observations:</u>

This study comprised of eight deployments over the course of three days with four during high tide and four during low tide. The data from one of the low tide drops was not usable due to a storm that occurred at the same time, which negatively impacted the visibility and made it impossible to determine which species were present. For this reason, the final data only included seven drops. Also, any species with single occurrences were removed from the data. There were certain important observations that the data revealed applied to every drop. Each time the BRUV was brought back up, the bait bag was never completely emptied of bait, regardless of the tide level. Video analysis provided evidence that there was community sharing of the bait bag rather than certain species dominating or participating in antagonistic behavior. There was an overall lack of typical predatory behavior because fish fed on discards instead of hunting for prey. Another common observation was that each time that was marked for ferries arriving and leaving corresponded with the fish species dispersing away from the bait bag. The fish returned to their previous behavior surrounding the bait as soon as the ferries finished coming in or leaving the dock.

Tables and Figures:

The data table was constructed with five columns for the species names, the average max N value at high tide, the average max N value at low tide, their primary diet in terms of being either herbivorous, carnivorous, or omnivorous (H, C, or O), and whether or not they feed on the discards. Not all species seen and counted in the table fed on the bait. Of those that did feed on the bait and became scavengers, six were primarily carnivores, two were herbivores, and two were omnivores. High tide received the majority of the carnivorous and omnivorous species as well as all of the herbivorous species. This table includes each species that was seen in the BRUVS frame-by-frame analysis (more than once) and is used to construct the figures that allowed the data to be conceptualized (Table 1).

Table 1: Average maximum N for species recorded by BRUV system at high and low tides with regard to their diet and whether they fed on the bait

Species	AVG MaxN HT	AVG MaxN LT	Primary diet (H/C/O)	Feeds on discards (Y/N)
Sphyraena obtusata	8	0	C	Y
Siganus fuscescens	26.25	9.75	H	Y
Alepes apercna	0.5	0.75	C	Y

Pseudolabrus guentheri	2.75	1.75	C	Y
Thalassoma lunare	0.75	1.5	C	N
Abudefduf bengalensis	5.25	3.5	O	Y
Microcanthus strigatus	3.25	10.5	O	Y
Chaetodon vagabundus	1	0.5	O	N
Chelmon rostratus	0.5	0	C	N
Pentapodus paradiseus	4.25	0.25	C	Y
Rhabdosargus sarba	3.5	0	H	Y
Acanthopagrus australis	3.75	1.5	C	Y
Lutjanus fulviflamus	1.25	2	C	Y
Chrysophrys auratus	7	3	C	N
Silago ciliata	0	0.25	C	N

The first three figures constructed pertain to organizing the overall data in a way that allowed meaningful patterns to become clear. The Bray-Curtis dissimilarity matrix clustered the variables, which are the different species, following a square root transformation. The matrix also allowed for the generation of a non-metric Multidimensional scaling plot (nMDS), which showed the distribution of different species based on tide height and species abundance. Each dot in the figure represents a species and its placement along the x-axis indicates abundance, while its placement along the y-axis represents tide height. Further left dots indicate higher abundance and abundance decreases as the graph moves right. The higher up species are from high tide data and the species lower down on the figure are from low tide data. This figure showed the variety in species recorded and how they were distributed in the tides. For example, the species *Microcanthys strigatus*, abbreviated as “microst” is in the lower left corner, which indicates that this species is in high abundance during the low tide. This figure also showed a stress of 0.13, which correlates to low stress since it is less than 0.2. The meaning of low stress is that there are not many other ways to rearrange the data so this arrangement is a good fit and thus an accurate way to portray the data. In order to further understand the differences in abundance, we calculated the estimated minimum fish abundance for low tide to be 47.33 ± 5.03 and for high tide, it was 69.50 ± 9.47. This value demonstrates that the minimum fish abundance is higher for high tide than low tide.

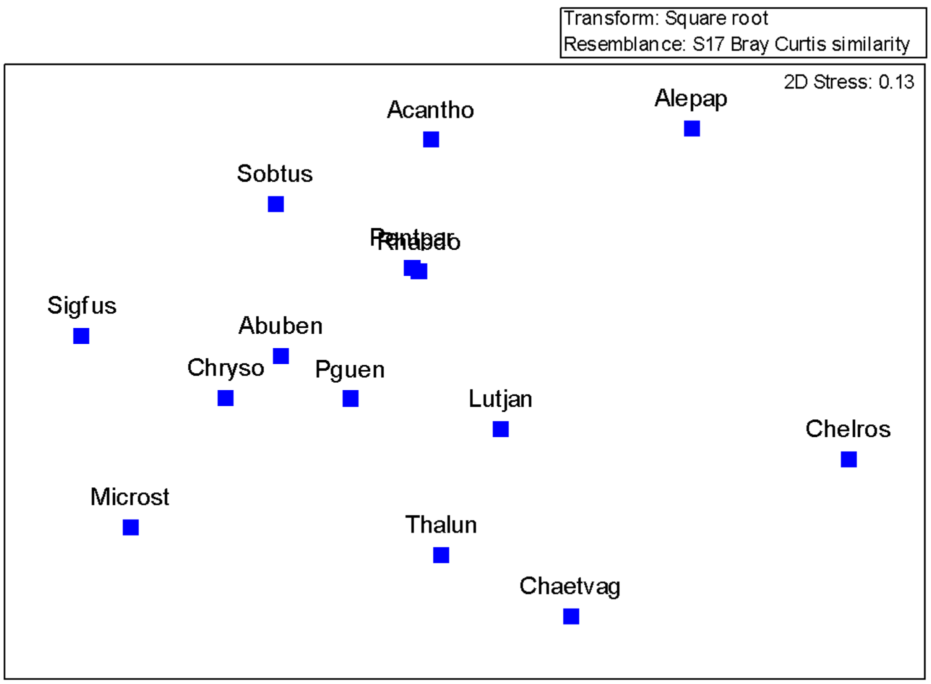

Figure 1: Scatterplot using non-metric Multidimensional Scaling plot (nMDS) showing the distribution of different species based on abundance (x-axis) and tide height (y-axis)

The second figure is another way to portray the data in the form of a scatterplot that was constructed in N-1 dimensional space that compares the BRUV drops. Each dot in the plot represents one of the drops with the color indicating whether it was a high tide or low tide drop. The closer the dots are, the more similar they are to each other. The figure shows that there was a significant separation between the high tides and the low tides since each group is clustered on different sides. There was a statistically significant difference between the two and there was an outlier for the low tide data.

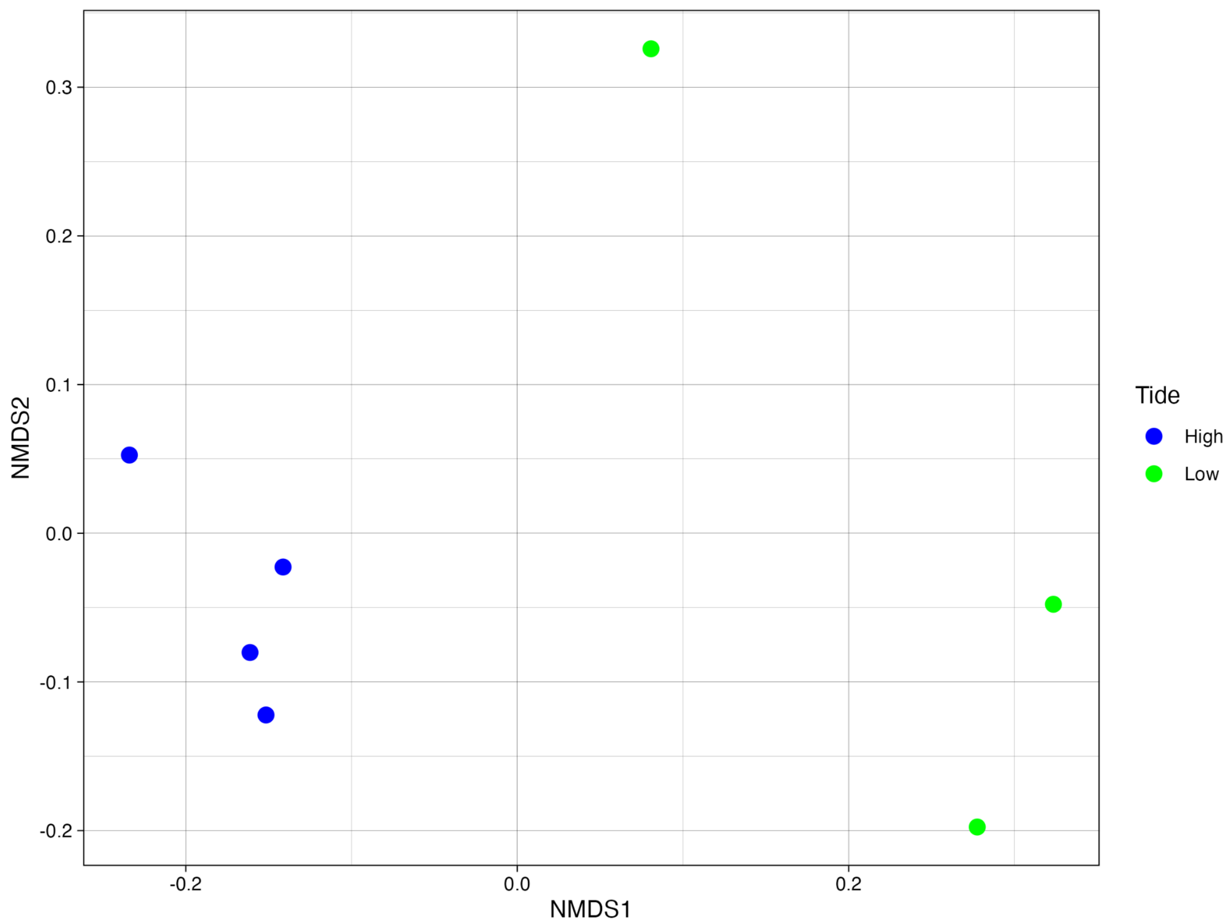

Figure 2: Scatterplot in N-1 dimensional space that compares BRUVS drops in multidimensional space (high tide and low tide)

The third figure compares the species richness for high tide drops and low tide drops. The error bars are included to show the standard deviations for each data set. The error bars for low tide and high tide overlap, which means that the differences in the bar graphs are not statistically significant. Even though it appears that there are more species observed in high tide, our statistical error is such that there could be the same number of species seen for low tide. This results in there being no statistical difference in species richness between high and low tides.

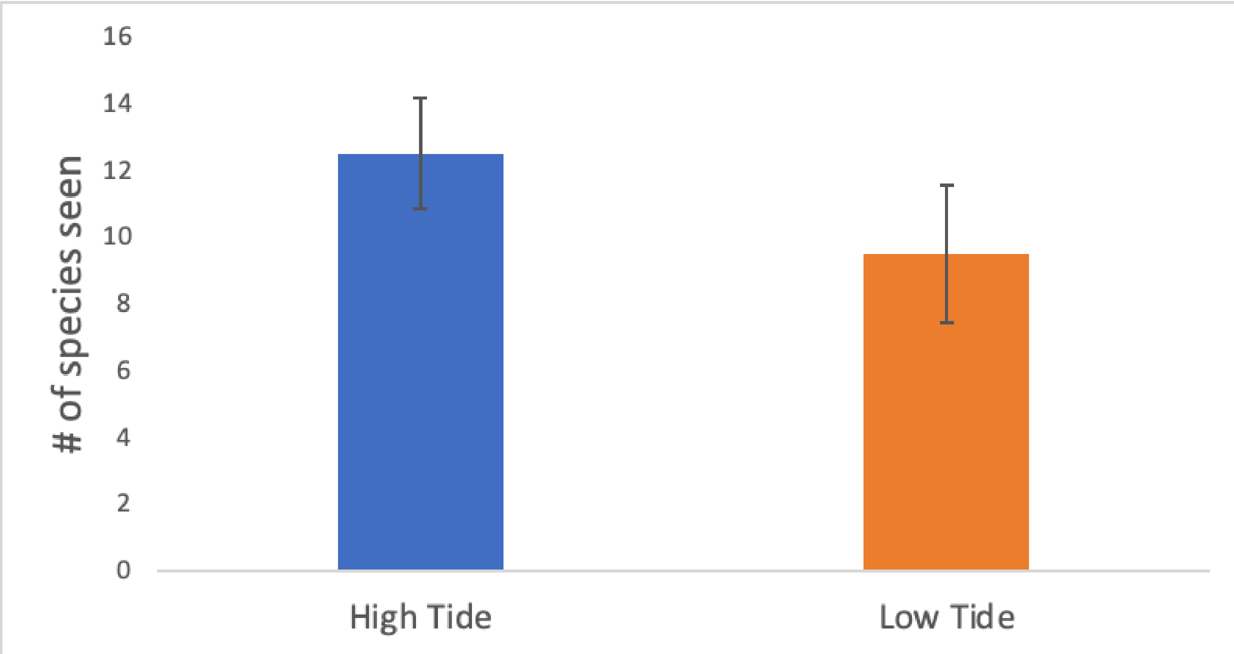

Figure 3: Bar Graph comparing species richness by showing the number of species recorded for high tide compared to the number for low tide

DISCUSSION

Based on the data, the table, and the figures constructed, there can not be direct conclusions made that fishery discards have an impact on species richness and abundance at high and low tides. The third figure does not show statistical significance in terms of greater species richness at high tide compared to low tide (Fig. 3). In order to differentiate between the species richness in terms of the number of different species recorded at high and low tides, more replicates would be necessary (Cappo et al. 2007).

Tides did, however, appear to influence the distribution of species, as indicated by the second figure, where low tide data and high tide data clustered on opposite sides of the plot (Fig. 2). The exception to this was the low tide data outlier, which could be attributed to the fact that one of the most abundant species in high tide, *Siganus fuscescens*, was seen during that drop with high abundance (Table 1, Fig. 2). This outlier does not affect the portrayal of the high and low tide data being dissimilar, especially considering outliers are a common occurrence in BRUVS data (Currey-Randall et al. 2020). Therefore, the separation of the high and low tide data suggested that tide was a strong driver of the community structure in terms of fish assemblages.

Based on the findings that species composition was distinct between high and low tides, tides are a driving factor in the change in community compositions, specifically in terms of what species are present in an area (Fig. 1, Fig. 2). Since tides cause environmental changes in the intertidal zone, many marine species must be able to adapt and synchronize their habits by migrating with the tides (Gibson 2003, Lee et al. 2014). The concept of tidal migration was supported by the results of this research, which highlights differences in species during high and low tides (Gibson 2003, Miller et al. 2009).

Certain species being more prominent at high or low tide alludes to what preferences that species has or what conditions they are able to withstand (Gibson 2003, Lee et al. 2014, Martin 1995). During low tides, intertidal regions subject organisms to high levels of ultraviolet radiation, high temperature, and low oxygen levels, potentially leading to issues like desiccation and hypoxia (Martin 1995, Miller et al. 2009). This relates to why the species *Microcanthus strigatus* was found in higher abundance at low tide. At low tide, it ranked as the most abundant out of thirteen species, whereas at high tide, it was eighth most abundant out of nineteen. *Microcanthus strigatus* has been known to be found in environments affected by tidal changes, such as rock pools, because it possesses adaptations to the physiological limitations that are imposed (White et al. 2014).

Based on the data, it was evident that other species, specifically the usually herbivorous *Siganus fuscescens*, were more than twice as likely to be found at high tide instead of low tide (Table 1). This connects to the finding that herbivorous fish migrate into intertidal zones during high tides in order to feed and avoid predation in deeper waters (Gibson 2003). The results further support this notion, as all of the other herbivorous species were only recorded to be present during the high tide drops (Table 1). These four herbivorous species must have migrated into the intertidal zones leading up to high tide, which aligns with research that found herbivorous fish density increased with depth, particularly as the tides are rising (Lee et al. 2014).

The fact that herbivorous fish seem to migrate in with the high tide correlates with the finding that the estimated minimum fish abundance is higher for high tide (Gibson 2003, Lee et al. 2014). Two of the five herbivorous fish species including *Siganus fuscescens* were recorded to feed on the bait during the high tide drops, altering their typical habits from herbivory to scavenging (Table 1). This demonstrates that the presence of fishery discards did change the feeding behavior and consequentially the trophic levels of certain species (Table 1).

The potential problem with changes like this is that they upset the delicate balance of the intertidal trophic food web (Lee 2014). If herbivorous fish species usually feed by grazing, they keep certain producer species in check (McQuaid and Branch 1985). Producers like algae could overgrow if their predators focus on other food sources (Cubit 1984). The role of discards can therefore go from causing a small change to resulting in a cascading effect that goes up through the trophic levels (Lee 2014). To clarify, not all the herbivorous species were equally affected so we cannot conclude that fishery discards directly resulted in herbivorous species becoming scavengers.

The practice of continuing to monitor the impacts of fishery discards in areas that are heavily affected is of high importance (Bellido et al. 2011). It is also relevant to realize that since fishery discards have been impacting ecosystems for a long period of time, many of these communities are already dependent on them (Heath et al. 2014). Thus, eliminating fishery discards is not a viable option or recommendation for the future. Future regulations should advise and ensure that fishery discards do not increase or begin in new locations. This would prevent ecosystem dependence on fishery discards from increasing (Bellido et al. 2011, Heath et al. 2014). Experiments that hope to uncover what specific changes the impacts of fishery discards will incur on intertidal trophic levels and their ecosystems' communities should specifically focus on the herbivorous fish species that fed on the bait. By following these species, potential research studies could explore the factors that alter the feeding habits of species that have been and continue to be exposed to fishery discards.

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