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Fish use of largely unexplored sub-tidal habitats in the Hinchinbrook Channel Estuary, Queensland

Alexandra Parisien
SIT Study Abroad

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Parisien, Alexandra
Academic Director: Brennan, Peter
Project Advisor: Penrose, Helen
Duke University
Environmental Science
Australia, North Queensland
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ISP Ethics Review

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ABSTRACT

This study examines the use of sub-tidal open-bottom, rocky, and seagreass habitats by the *Siganus* genus (herbivores), *Gerres* genus (benthivores), and planktivores in the Hinchinbrook Channel Estuary in Queensland, Australia. The Hinchinbrook Channel Estuary, a tropical estuary cutting between Hinchinbrook Island and the Australian mainland, is surrounded primarily by mangroves. Its sub-tidal habitats are largely unexplored due to factors such as low visibility and the presence of estuarine crocodiles. In this study, I reviewed 699 underwater videos collected by James Cook University PhD candidate Michael Bradley in order to analyze feeding and movement behavior of pre-identified fish.

The results of this study show that Siganids feed mostly in seagrass areas but are often present in rocky areas, potentially using the rocky structures as protection and refuge. Gerres also feed mostly in seagrass areas but also feed in open-bottom areas, which suggests that while seagrass areas are important, even habitats that appear barren provide service to certain fish. I observed Gerres searching on the benthos in all habitats but did not see them feed in rocky habitats, and they were seldom sighted there. Planktivores, on the other hand, feed most often in rocky habitats and also feed occasionally in the other two habitats, suggesting a need to apply conservation efforts to all of these sub-tidal habitats. The videos revealed site-attached behavior (when fish remain in the same area for an extended period of time) mostly in rocky areas yet at least some site attachment in all of the habitats, again suggesting that all hold some importance for fish.

Understanding the use of sub-tidal habitats by these particular groups of fish is important, as they all are connected to other habitats like coral reefs through their movement and feeding, and thus the habitats studied affect these other ecosystems. Understanding these connections can help inform management techniques to maintain maximum connectivity and increase resilience of the ecosystems. I recommend management techniques including stringent fishing and recreation rules in the Hinchinbrook Channel and a reduction in agricultural chemicals used in the surrounding areas. I also recommend further research on other habitats and fish species in the estuary and similar research in other estuaries.

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ACKNOWLEDGEMENTS

First and foremost, I would like to thank Michael Bradley of James Cook University for allowing me the use of his videos, and for providing guidance and assistance every step of the way in my research. Thanks also to Martha Brians and Marcus Sheaves at James Cook University for helping me formulate my research question and giving me valuable advice. Also, I wish to thank my advisor Helen Penrose, who offered a wealth of information including research ideas, contacts, and articles, and answered my many questions along the way. Finally, I extend my gratitude to Peter Brennan, the Academic Director of SIT Australia: Sustainability and Environmental Action, who served as a great source of inspiration and pointed me in the right direction throughout the Independent Study Project process.

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Study System

An estuarine system is defined by Kjerfve as a "coastal indentation that has a restricted connection to the ocean and remains open at least intermittently" (Kennish, 2002, p. 79). The Hinchinbrook Channel (shown in Figure 1), an estuarine body cutting between the mainland of Eastern Australia and Hinchinbrook Island, runs more than 40 kilometers long (Estuary and Coastal Wetland Research Group, n.d.). At -18.258 degrees latitude in Queensland, Australia, it has a wet tropical climate and thus supports a wide range of tropical flora and fauna (Geoscience Australia, n.d.). According to Geoscience Australia, it is surrounded by approximately 93 percent mangrove and 7 percent salt marsh, with extensive seagrass beds present on the floor (n.d.). Because its state has been assessed as being "largely unmodified" (Geoscience Australia, n.d., p. 1), it contains relatively pristine estuary ecosystems for study.

Figure 1: Map depicting Hinchinbrook Island and Hinchinbrook Channel in North Queensland. Map from Crackajack Sportfishing Adventures, n.d.

1.2 Importance of Study System

The habitats studied in the Hinchinbrook Channel estuary could serve many important functions for marine life in the area. For example, according to Nagelkerken, Sheaves, Baker, and Connolly, estuarine ecosystems can serve as productive and vital nurseries for juveniles (2013). This is because they are separated and buffered from the ocean, and thus juveniles and breeding adults are not subject to the same risks that exist in the open ocean (U.S. EPA, n.d.). While the precise definition of a marine nursery can be debated (Nagelkerken et al., 2013, p. 3), it can generally be defined as a habitat in the seascape that "contributes a greater than average number of individuals to the adult population on a per-unit-area basis in comparison to other habitats used by juveniles" (Dahlgren et al., 2006, p. 292). These nurseries, often providing food and refuge (Sheaves, Baker, and Johnston, 2006, p. 304), play an integral part in maintaining a healthy adult population.

Estuaries like the mangrove-surrounded Hinchinbrook Channel estuary are also important feeding grounds for many species of marine life (Sheaves, 2005, p. 293). Mangroves have high rates of primary production and provide a great deal of organic carbon to ecosystems like those in the Hinchinbrook Channel (Burford, Alongi, Mckinnon, and Trott, 2008, p. 440). In addition, there is a rich benthic invertebrate variety near mangroves, providing sustenance for larger fish species (Sheaves, 2005, p. 293).

In addition to the shallow water habitats provided by its surrounding mangroves and salt marshes, the channel also contains many deeper water habitats and is more than 20 meters deep in some areas (Estuary and Coastal Wetland Research Group, n.d.). These habitats include silt with seagrass cover, silt with algal cover, bioturbated silt, bare silt, silt with sponge cover, bare gravel, rocky areas with algal cover, and rocky areas with sessile invertebrate cover (Bradley, 2013, p. 20). According to Bradley, the uses of many of these habitats to fish species have been researched very little and remain largely mysterious to the scientific world (2013, p. 21).

1.3 Threats to the Study System

The habitats within the Hinchinbrook Channel, while relatively unharmed by human activity, have seen some degradation, primarily due to agricultural land use in the surrounding area (Geoscience Australia, n.d. p. 1). While the area is still relatively healthy compared to many other degraded habitats on Earth, continued agricultural use could have dire consequences. Nutrient enrichment, which can occur when runoff carries fertilizers from farms into the water, is "one of the most serious threats to near shore coastal ecosystems," with consequences such as algal blooms, reef degradation, loss of diversity and resilience, and eutrophication resulting in dead zones (Lovelock, Ball, Martin, and Feller, 2009, p. 1). Climate change poses threats to surrounding mangroves due to increasing water and sediment salinity from decreased humidity and rainfall (Lovelock et al., 2009, p.1). Moreover, greater boat traffic in the channel due to development of new marinas and boat ramps could endanger marine life and ecosystems (Preen, 2001, p. 1). The additional traffic and noise created by these sources particularly affect large marine life like dolphins and dugongs in the channel, which could throw out of balance the ecosystems and harm other species secondarily (Preen, 2001, p. 2). These risks to estuaries, among others, are expected to become more acute over the next several years, as the coastal population around the world is rapidly growing and is expected to exceed 6 billion people by the year 2025 (Kennish, 2001, p. 79).

Seagrass bed damage in the Hinchinbrook Channel is of especially grave concern; Australia has the highest species diversity of seagrasses in the world (Carruthers et al., 2002, p. 1153), and the significant seagrass presence is threatened by a number of environmental and biological stressors (Orth et al., 2006, p. 987). Seagrasses suffer in more acidic and lower quality water created by climate change and anthropogenic pollution (Orth et al., 2006, p. 991). They also suffer from increased turbidity, as witnessed with the large loss of seagrass beds following the passage of tropical storms in Hervey Bay, Australia (Orth et al, 2006, p. 991). In addition, seagrass habitats are under threat due to trophic cascades leading to the loss of species higher in the food chain, allowing species that consume seagrass to flourish (Orth et al., 2006, p. 991). These fish higher in the food chain are often overfished by humans or struggle in the increasingly severe environmental conditions (Orth et al., 2006, p. 992).

1.4 Fish Presence

Fish constitute about 99 percent of the nektonic species in estuarine environments, and thus play a very significant role (de Paiva, Lima, Souza, and de Araujo, 2009, p. 266). Within the 54 marine taxa identified in preliminary research by Michael Bradley, there were 56 species of fish, 23 of which had never been previously recorded in estuarine fauna in North Queensland (Bradley, 2013, p. 46). The Hinchinbrook Channel contains fish species from all trophic levels, from small planktivorous and herbivorous fish to predatory snappers like those in the *Lutjanus* genus (Bradley, 2013, pp. 46-47). This study focuses on fish that are herbivores, benthivores, and planktivores, as observing predator feeding in the videos was very rare.

Herbivorous fishes, like those present in the Hinchinbrook Channel, feed on a variety of algae and seagrasses (Horn, 1989, p. 134). Algae-eating fish usually have short snouts with closely set teeth for picking algae off where it is attached (Horn, 1989, p. 137). They can be classified either as grazers or browsers; grazers pick up inorganic substrate while only digesting the plant material within it, whereas browsers pick at larger plants like seagrasses and rarely ingest inorganic material (Horn, 1989, p. 138). Herbivorous fish play very important roles in ecosystems, including eating epiphytic algae off of light-limited seagrass (allowing the seagrass to grow) (Hauxwell, McClelland, Behr, and Valiela, 1998, p. 347), controlling the populations of seagrass (Hauxwell et al, 1998, p. 348), and serving as prey for larger fish (Qasim, 1970, p. 50).

Benthivores feed mainly on benthic invertebrates present on the seafloor, like crustaceans, polychaets, and bivalves (Zahorcsak, Silvano, and Sazima, 2001, p. 512). They generally feed by burying their mouths into the substrate and swallowing their prey along with some of the sediment, then ejecting the sediment from their mouths or through their gills, and they have sensorial appendices and inferior protractile mouths to aid with this feeding technique (Zahorcsak et al., 2001, pp. 512-513). These fish can limit invertebrate drift and apply top-down control on benthic invertebrate populations (Winkelmann, Petzoldt, Koop, Matthaei, and Benndorf, 2008, p. 484), and also serve as prey for other large fish and humans (Qasim, 1970, p. 50).

Planktivores are fish that feed on zooplankton and phytoplankton in the water column. They can be divided into the categories of filter feeders and visual feeders –

filter feeders strain prey from engulfed water using structures like gill rakes, whereas visual feeders directly target and attack single zooplankton prey (Lazzaro, Drenner, Stein, and Smith, 1992, p. 1467). Many of the planktivores sighted in the Hinchinbrook Channel are visual feeders that directly suppress populations of zooplankton, and may indirectly enhance phytoplankton populations and primary production (Lazzaro et al., 1992, p. 1467; Kingsford and MacDiarmid 1988, p. 103).

1.5 Significance of Research

In this study, I examine key feeding and movement behaviors in fish across a range of trophic levels and in a range of habitats. I will specifically answer the question: "How do herbivores, benthivores, and planktivores utilize open-bottom, rocky, and seagrass estuarine habitats in the Hinchinbrook Channel?"

This research is significant, as these habitats are very challenging to study, and thus very little is known about them. Figure 2 depicts the vast amount of the Hinchinbrook Channel that has yet to be fully explored. Obstacles to investigating these habitats include depth, low visibility, high turbidity, the presence of the crocodile *Crocodylus porosus*, and lack of adequate remote sampling technology (Bradley, 2013, p. 2). Yet understanding all of the individual habitats within a full ecosystem is critical to understanding the ecosystem as a whole, and this study begins to accomplish that through use of technologies such as sidescan sonar, remotely operated vehicles, and video drop cameras.

Since little is known about many of the deep-water estuarine habitats studied, this research can help establish vital conservation areas and serve to inform management techniques. Areas of critical importance due to feeding, breeding, or shelter opportunities, or due to connectivity to other habitats, could as a result of this research be conserved more stringently and effectively, leading to a healthier ecosystem. Therefore, this project advances the goal of supporting sustainability, or the ability of a system to persist and maintain itself. In addition, while fish do not necessarily behave in the same way in this particular channel as in other areas, this research can be used as a basis for beginning to understand marine life in deeper estuarine waters in other parts of the world (Bradley, 2013, p. 38).

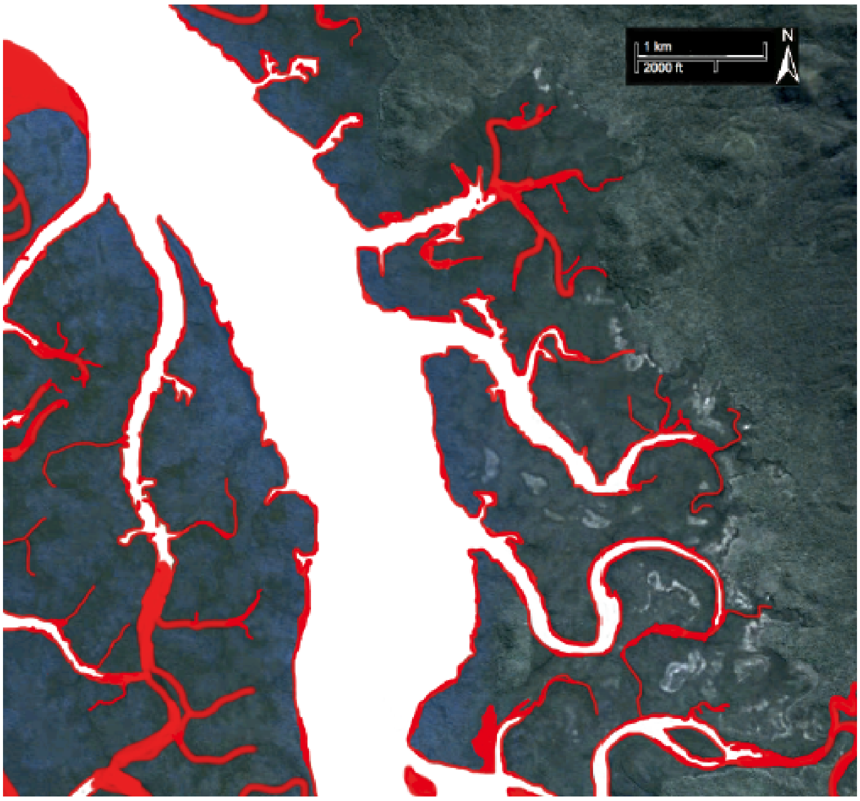

Figure 2: Areas studied versus areas unexplored. This image depicts part of the Hinchinbrook Channel. The areas highlighted in red represent the approximate areas in which researchers have an ecological understanding of fish and their habitats. The white section represents areas that have yet to be fully explored, and where the habitats in this study are located. Dark green areas are mangrove forests, and lighter green areas are terrestrial vegetation. (Bradley, 2013, p. 4)

2.0 METHODOLOGY

2.1 Habitat Data and Video Collection

The 699 ~15-20 minute videos reviewed in this study were collected by PhD candidate Michael Bradley of James Cook University in November and December 2012 (sites shown in Figure 3) and June-December 2014 (zones shown in Figure 4). Many techniques frequently used to survey underwater habitats, such as snorkeling and SCUBA, are made impossible in the Hinchinbrook channel due to factors like low visibility and the presence of predators such as estuarine crocodiles (Bradley, 2013, pp. 8-9). Therefore, Bradley collected videos and analyzed the habitat areas using a systematic multi-step technique involving sidescan sonar, remotely operated vehicles (ROVs), and video drop cameras.

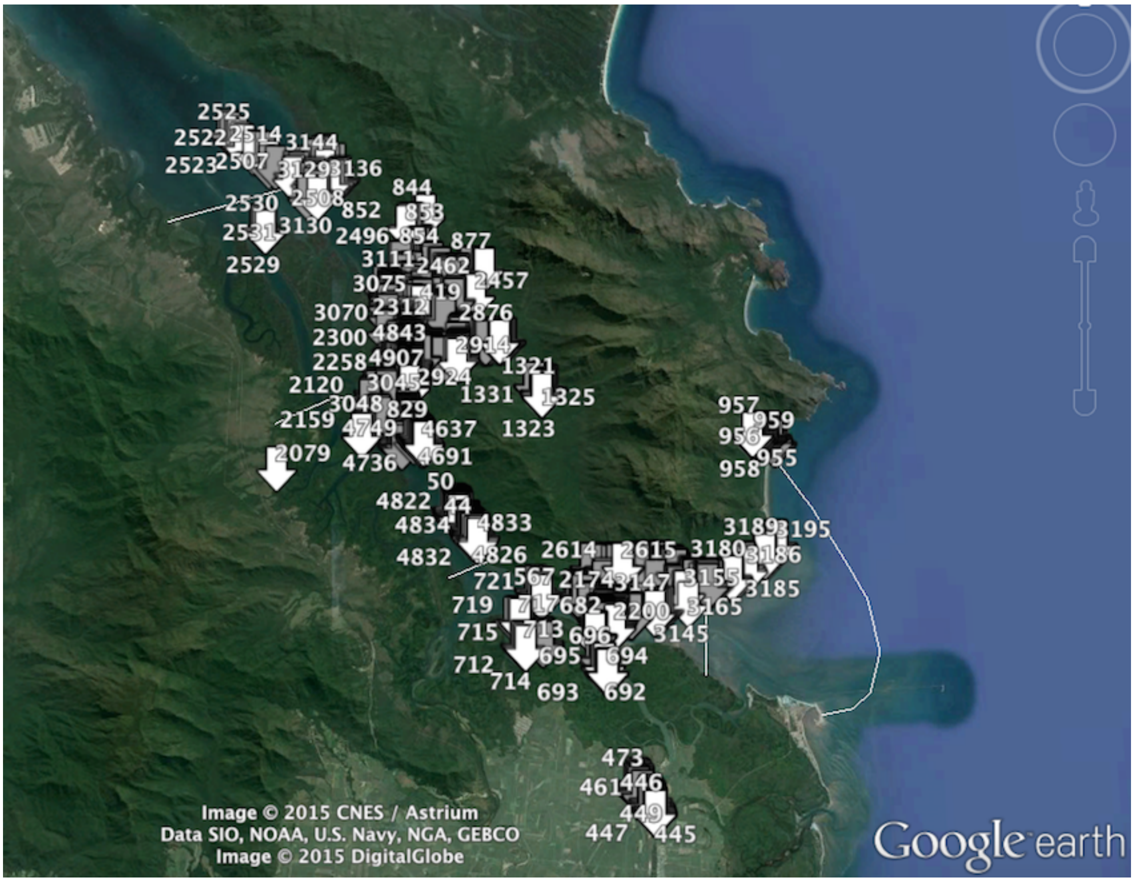

Figure 3: **Sites of videos collected in November and December 2012**. Sites scattered around the Hinchinbrook Channel. Image by Michael Bradley via Google Earth.

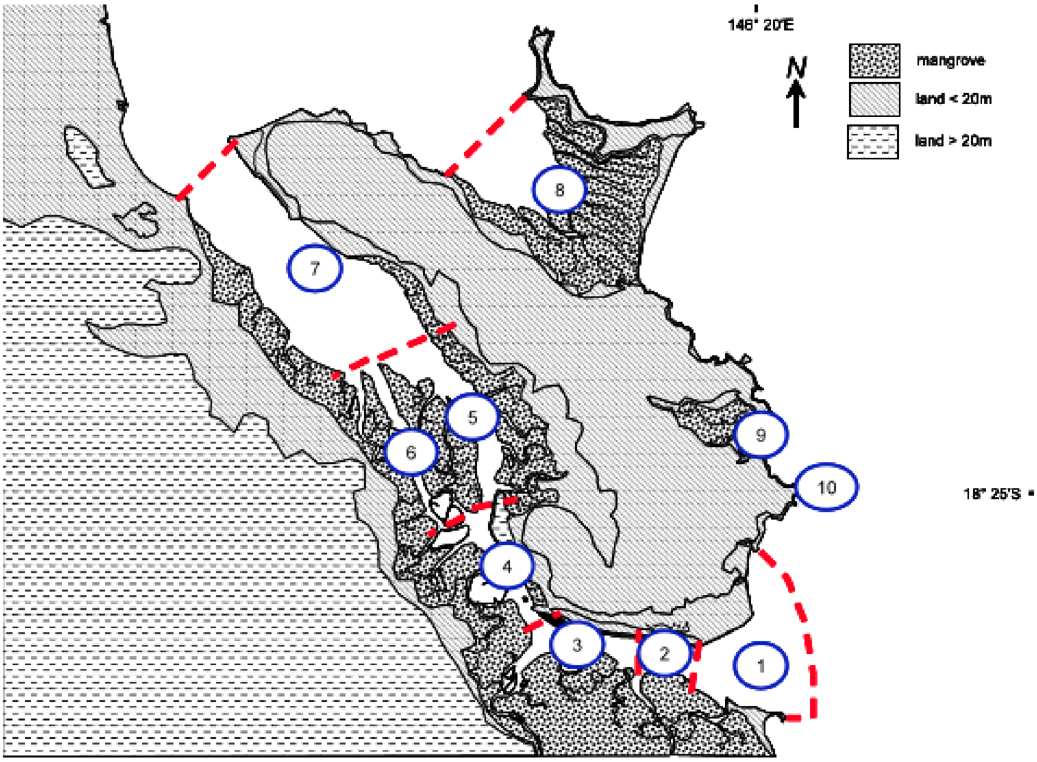

Figure 4: **Zones sampled in 2014, in the Hinchinbrook Channel and surrounding creeks**. Bradley sampled each zone comprehensively. Image by Michael Bradley.

Sidescan sonar emits sonar energy at low frequencies in order to produce a 2D image of the seafloor and identify various substrate types (Bradley, 2013, p. 12). This technique surveyed 80m wide swaths at a time, extending from the intertidal fringe to the bottom of the main channel. While this technique provides a broad view of the seafloor, it has some limitations, including low resolution, image distortion at far distances from the center of the swath, and inability to detect "acoustically soft" features such as vegetation (Bradley, 2013, p. 12). Thus the sidescan sonar was used mainly to inform the ROV surveys in order to collect data from the range of substrate types in each area. ROVs helped to provide a clearer picture of the benthos of the area being studied (Bradley, 2013, p. 14). While ROVs can be used to survey fish, their movement can frighten fish, and many fish were observed swimming away from the vehicle before they could be identified (Bradley, 2013, p. 15). Thus, Bradley used the ROV surveys mainly to inform the video drop camera surveys, by sampling across the full range of biotic characteristics seen in the ROV surveys with the video drop cameras. Bradley employed video drop cameras in order to gain an unbiased view of fish in each habitat (Bradley, 2013, p. 16). The videos were collected during daytime hours and at times of low tidal movement to maximize visibility, and each video ran for approximately 15 minutes (Bradley, 2013, p. 17). This hierarchical method of collecting data using these three techniques is shown in Figure 5.

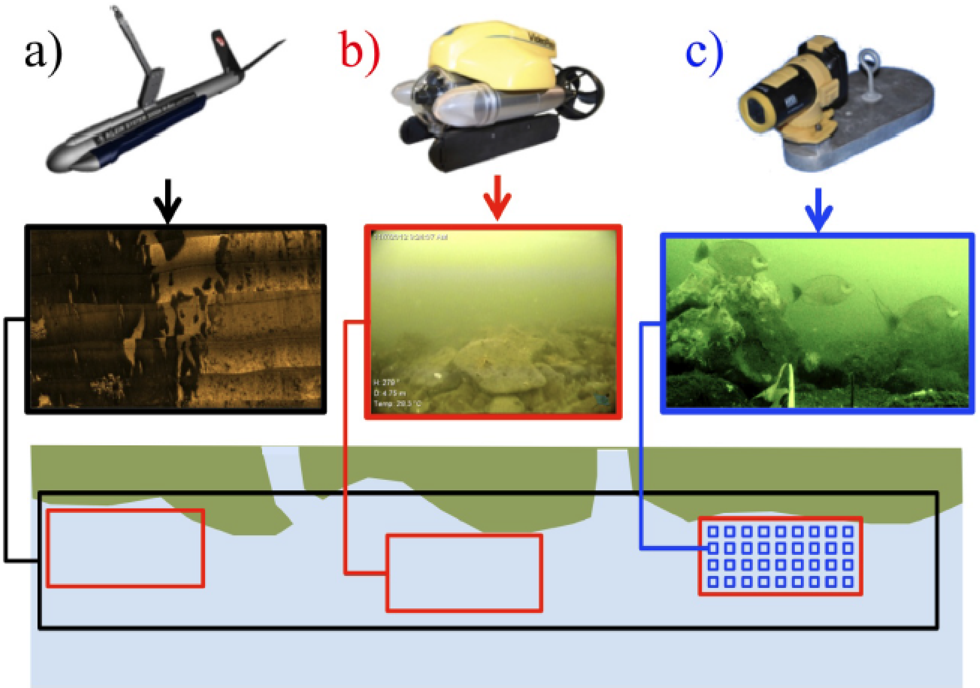

Figure 5: **The hierarchical technique used to survey the Hinchinbrook Channel**. A) shows sidescan sonar, b) shows the ROV, and c) shows the video drop camera. The upper panel is an image of the equipment itself, the middle panel shows its output, and the lower panel (with green representing the shoreline and blue representing the water) depicts the spatial scale at which the technique operates. The black box represents the spatial scale of the sidescan sonar, the red boxes the ROV, and the blue boxes the video drop cameras (Bradley, 2013, p. 11).

2.2 Fish and Habitat Identification

Bradley completed the identification of fish visible in the 2012 and 2014 videos. He identified fish to the most specific taxonomic category possible, and only identified a species if he could do so with total confidence (Bradley, 2013, p. 42). He was aided in identification by a variety of experts. Bradley recorded, among other information, the species observed, the numbers of fish, the sizes of fish, at what time in each video they were seen.

In 2012, Bradley categorized habitat type into the three broad categories of open-bottom, rocky, and seagrass, and in 2014, he placed habitats into the more specific categories of mud, sand, grit, gravel, rock, cobble, and seagrass. For the purposes of my study, mud, sand, grit, and gravel are grouped as “open-bottom” and rock and cobble are grouped as “rocky.”

2.3 Fish Behavior Analysis

2.3.1 Categorization

Using Bradley’s data sheets delineating the times of fish sightings in each video, I was able to observe each video at these specific instances to determine the feeding and movement behavior of the fish.

In terms of feeding behavior, most benthivores and herbivores were defined as either “feeding” or “not feeding.” Gerres feeding behavior was divided into three categories: “feeding,” “not feeding,” and “searching on benthos.” Gerres’ observed characteristic feeding behavior was observed to involve clear, long pauses to identify prey on benthos, followed by quick dives to catch the prey or continued swimming if no prey is present. Thus, Gerres were defined as “searching on benthos” when clear pauses were observed without diving down, and they were defined as “feeding” only when dives to the benthos were observed.

Planktivores were also split into the feeding categories of “feeding” and “not feeding.” They were recorded as feeding only when they clearly could be seen swimming in a way that suggested they were attacking plankton in the water column.

I divided all fish into the movement categories of “site attached” and “swimming through.” “Site attached” behavior was recorded when fish stayed in the camera frame for an extended period of time, and were obviously not just swimming past the area.

2.3.2 Recording and Species Selection

When multiple feeding or movement behaviors were observed in a single video, this was recorded. For the purposes of analysis, each behavior was only counted once per video, even if it occurred multiple times in the single video.

Upon preliminary analysis, I noted that fish in the *Siganid* genus and fish in the *Gerres* genus were some of the most abundant herbivores and benthivores, respectively, and decided to focus on them in analysis. I grouped all planktivores together, due to the observed similarities in feeding strategy and the large number of species.

2.4 Ethical Considerations

This research is ethically sound, as it involves minimal contact with the fish under observation, and thus a low potential for any disturbance or harm. Once the video cameras were in place, they were motionless for 15 minutes or more, and fish were observed going about their normal behavior with no concern for the cameras.

3.0 RESULTS

3.1 Siganids

3.1.1 Siganid Sightings

Of the 699 videos reviewed in this study, fish of the genus *Siganus*, known as rabbitfish, were identified in 45, or approximately 6.44%, of the videos. Species sighted included *Siganus javus, Siganus fuscescens, Siganus lineatus, Siganus spinus,* and *Siganus virgatus*. As shown in Figure 6**,** while in open-bottom and seagrass habitats non-feeding Siganids were identified in 1.86% and 3.92% of videos respectively, they were observed in 12.12% of all rocky-bottom habitats.

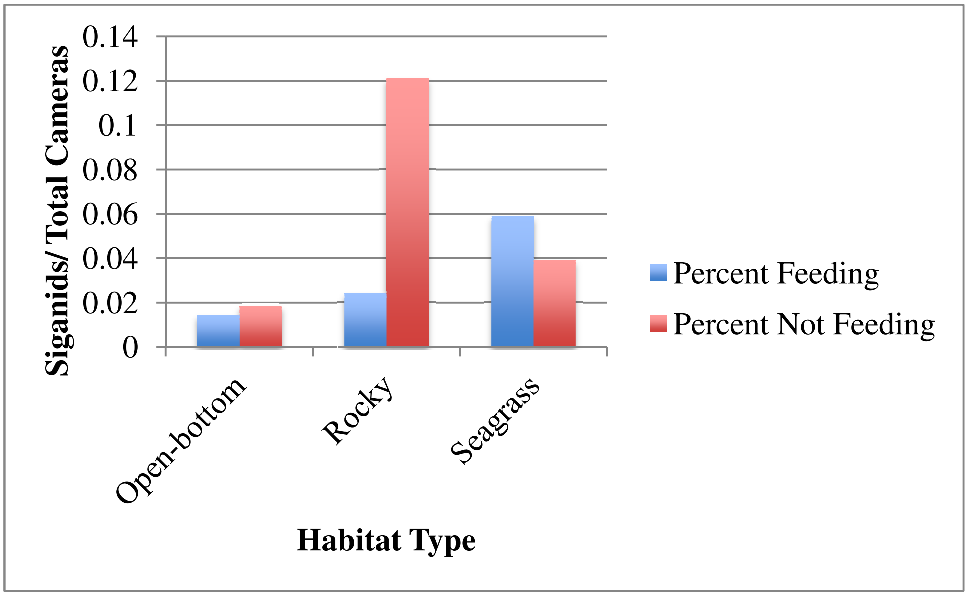

Figure 6: Proportion of videos in which feeding and non-feeding Siganids were identified, by habitat type

3.1.2 Siganid Feeding

However, a different pattern was observed when focusing on the presence of feeding Siganids. They were seen feeding in a total of 14 videos (~2% of total number of videos). Siganids were observed feeding in 5.88% of the 51 videos taken in a seagrass-bottom habitat, as compared to 2.42% feeding in the 165 rocky-bottom videos, and 1.45% feeding in the 483 open bottom (mud, sand, silt, and gravel) videos. Charts displaying the raw data collected are shown in Appendix A: Siganid Feeding Charts.

As shown in Figure 7, if a Siganid is in either an open-bottom or seagrass habitat, it has relatively similar chances of feeding versus not feeding (43.75% vs. 56.25% for open-bottom, 60% versus 40% for seagrass). However, a Siganid found in a rocky habitat, while they observed there frequently, is much less likely to be feeding (a 16.67% chance).

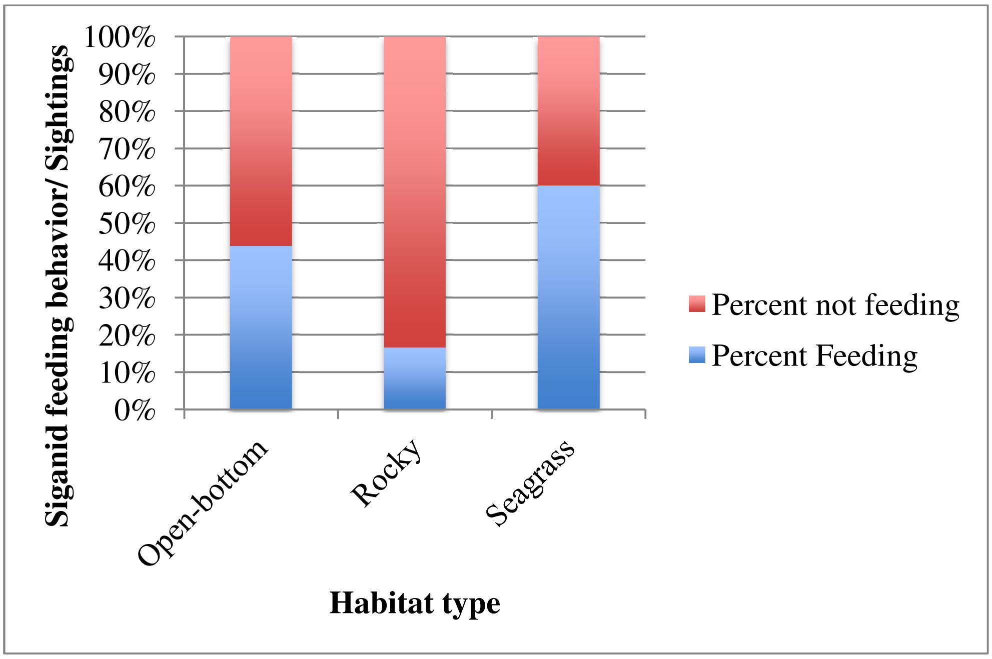

Figure 7: Percent of Siganids feeding and not feeding per number of Siganid sightings in each habitat type.

3.2 Gerres

3.2.1 Gerres Sightings

Of the 699 videos reviewed, fish of the *Gerres* genus were identified in 58, or approximately 8.30%, of the videos. The two species of Gerres identified in the videos were *Gerres filamentosus* and *Gerres oyena*. Sightings of Gerres not displaying feeding behavior remained relatively constant across the three habitat types, with non-feeding Gerres seen in 1.86% of open-bottom habitat videos, 1.21% of rocky-bottom videos, and 1.96% of seagrass-bottom videos, as shown in Figure 8.

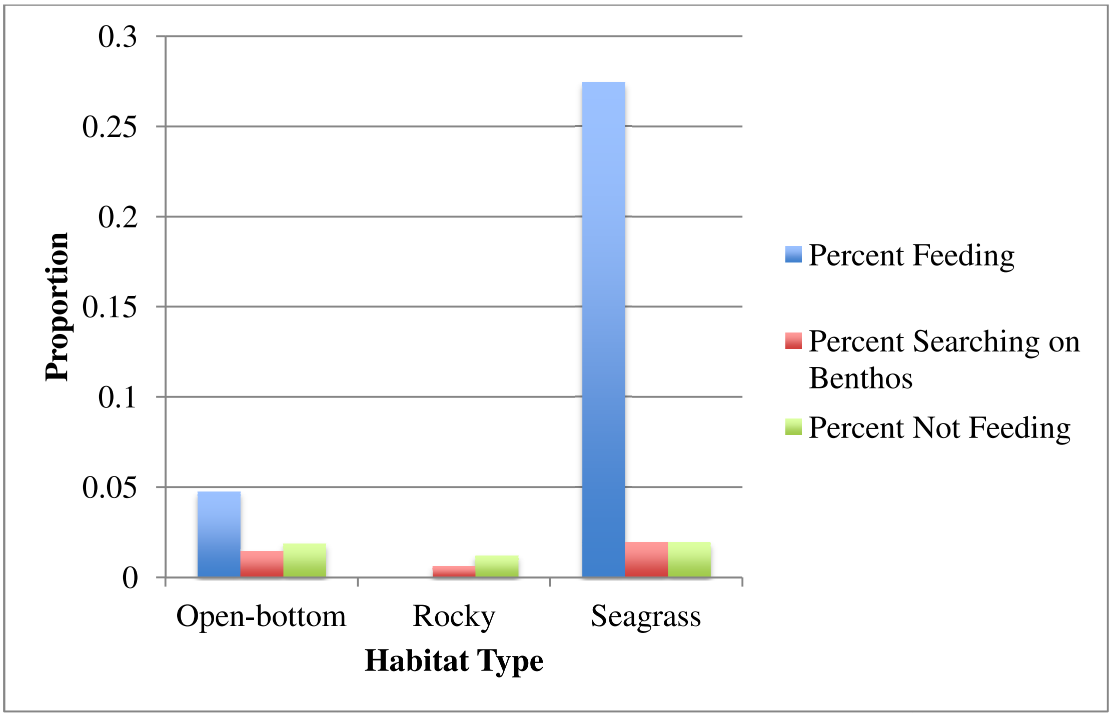

Figure 8: **Proportion of videos in which Gerres were seen feeding, searching on benthos, or not feeding by habitat type**

3.2.2 Gerres Feeding

However, a clear pattern emerged in Gerres feeding. As seen in Figure 8, Gerres overwhelmingly prefer feeding in seagrass habitats, with 27.45% of all videos taken in seagrass-covered areas showing feeding Gerres. In contrast, only 4.76% of open-bottom videos had at least one instance of feeding Gerres, whereas no Gerres were seen feeding in rocky habitats. Gerres were seen searching on the benthos in 1.45% of open-bottom videos, 1.96% of seagrass videos, and only 0.61% of rocky-bottom videos. Charts displaying the raw data can be found in Appendix B: Gerres Feeding Charts.

3.3 Planktivore Feeding

Planktivores also displayed feeding preferences. All species of planktivores were seen feeding in 85 of the 699 videos, or 12.16%. There were several species of planktivorous fish seen, including *Neopomacentrus bankieri, Neopomacentrus taeniurus,* and fish in the Clupeidae family. As shown in Figure 9, they fed most in the rocky areas, with 26.06% of rocky-bottom videos containing at least one instance of planktivore feeding. They also gravitated to seagrass habitats, with 15.69% of seagrass videos containing at least one instance of planktivore feeding. In open-bottom habitats, they were only seen feeding in 7.04% of the videos. A chart displaying the raw data can be found in Appendix C: Planktivore Feeding Chart.

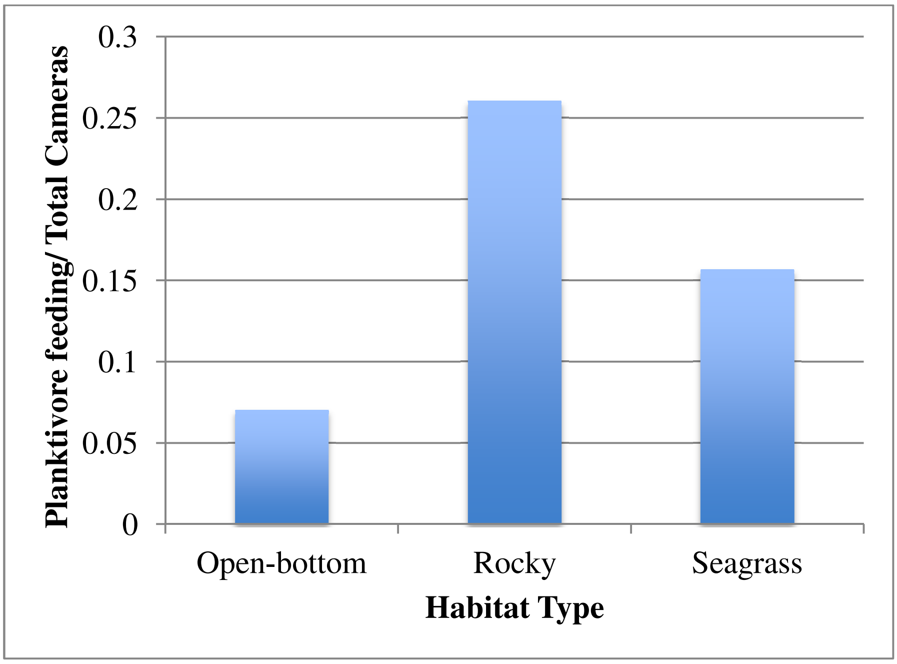

Figure 9: **Proportion of videos in which planktivores were seen feeding, by habitat type**

3.4 Movement Behavior

Site-attached behavior was observed in all habitat types. Across the three habitat types, it was witnessed 40 times, or in 5.72% of total videos. As seen in Figure 10, site-attached behavior was displayed in 4.55% of open-bottom videos, 9.09% of rocky-bottom videos, and 5.88% of seagrass-bottom videos. A chart displaying the raw data is shown in Appendix D: Movement Behavior Chart.

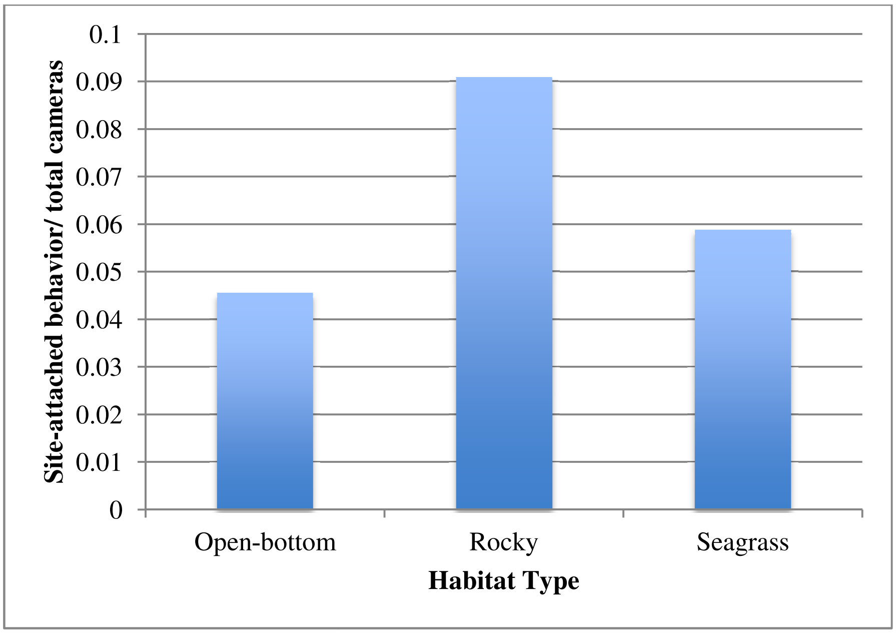

Figure 10: **Proportion of site-attached behavior per total videos by habitat type**

4.0 DISCUSSION

4.1 Siganid Sightings and Feeding Implications

This study has several implications for the individual fish studied, as well as for the ecosystem in the Hinchinbrook Channel and the surrounding marine ecosystem. The study shows that for the Siganids in the Hinchinbrook Channel, and potentially other herbivores, deep-water seagrass habitats are extremely important for feeding. This makes sense, as most fish in the *Siganus* genus are categorized as "browser" herbivores that pick at larger pieces of vegetation rather than sorting through sediment (Horn, 1989, p. 140). It is also clear that although they are seen quite frequently there, Siganids do not eat frequently in rocky habitats. I hypothesize that Siganids could be using the structure of the rocks as shelter and protection from predators or other threats in the open water, and therefore, the rocky habitat could be just as important to them as the seagrass. In addition, many species of fish have been found to stay in highly structured environments, like rocky areas or reefs, during the day, and feed in the seagrass at night (Kopp, Bouchon-Navaro, and Bouchon, 2007, p. 34). I hypothesize that if I had access to videos taken during nighttime hours, there may have been less Siganids in the rocks and more feeding in the seagrass.

4.2 Gerres Sightings and Feeding Implications

For the two species of Gerres present in the Hinchinbrook Channel (*Gerres filamentosus* and *Gerres oyena*), seagrass is also an extremely important component for feeding. These results make sense, as tropical seagrass beds are known to support great amounts of invertebrate life, and Gerres are benthivores (Heck and Wetstone, 1977, p. 141). While the diets of Gerres are largely unstudied, one stomach content analysis study suggests that both *Gerres oyena* and *Gerres filamentosus* feed largely on polychaets, oligochaets, and siphon tips, all of which would be in abundance in a healthy seagrass bed (Cyrus and Blaber, 1983, p. 378). In addition, these fish do make use of the open-bottom habitats for feeding, which suggests that even the least complex seeming habitats provide feeding opportunities for fish, and are important parts of the ecosystem.

4.3 Planktivore Feeding Implications

Planktivores also feed frequently in seagrass areas but make most use of the rocky habitats to feed. We may see the pattern of planktivores feeding most in rocky areas due to the specific nature of planktivores' prey. Unlike herbivores and benthivores, the prey of planktivores (plankton) is very mobile and moves around with currents and tides (Lazzaro et al., 1992, p. 1467). While there may not be more plankton in rocky areas than in open-bottom or seagrass habitats, planktivores could be staying in rocky areas for other reasons, like shelter and refuge. They are able to stay and feed in this area, as they could receive a constant supply of plankton through water movements.

4.4 Movement Behavior Implications

Site-attached behavior while feeding could suggest that the site is particularly rich in food for the particular species, and thus of high importance. Site-attached behavior was observed most in rocky habitats and slightly less in seagrass and open-bottom habitats. Site-attached behavior may also exist mostly in rocky areas, since these provide protection to fish, and therefore they may be more able to stay for longer periods of time. Since site-attached behavior was displayed in all of thee habitats, it appears that all of the habitats can provide rich feeding opportunities for fish.

4.5 Connectivity

Because most estuarine fauna are dependent upon more than one habitat at different life stages and for various uses, connectivity between habitats is an important area of study and is important to consider in this research (Sheaves, 2009, p. 108). Connectivity is most obviously observed by the movement of animals from one habitat to another, and can have effects on factors such as nutrient transport, life history strategies, and predator-prey interaction (Sheaves, 2009, pp. 109-112). According to Grober-Dunsmore, Pittman, Caldow, Kendall, and Frazer, highly mobile animals like the fish in this study can connect habitats through "daily foraging movements, including tidal and diel migrations, as well as, broader scale excursions for spawning and seasonal migrations" (2009, p. 493). Because connectivity and use of various habitats across the "coastal ecosystem mosaic" changes from species to species and over time depending on life stage and other conditions, such study is complex (Sheaves, 2005, p. 294). A broad look at habitats and their connectivity implies the need for a focus not only on individual habitat units, but also on the ways in which they are connected (Sheaves, 2009, p. 112).

Connectivity is a major topic to explore in terms of the fish and habitats studied in this research. For all species or groups studied, fish take advantage of all or almost all of the habitat types (open-bottom, rocky, and seagrass), and therefore all of these habitats are connected through these animals. These habitats could also be connected to other more spatially distant habitats through fish movement. For example, in addition to feeding heavily in seagrass areas and potentially seeking refuge in rocky areas, many species of Siganids are frequently present and feeding on coral reefs like the Great Barrier Reef (Huse and Toresen, 1996) and thus play a role in this important and fragile ecosystem as well. Species in the *Gerres* genus are also frequently found in coral reef and mangrove systems, playing some role in these areas (Halpern, 2004). In addition, many of the frequently sighted planktivores are often found on coral reefs, like *Neopomacentrus bankieri* (Solitary Island Underwater Research Group, n.d.) or are migratory like Clupeids (Laroche and Ramananarivo, 1995).

4.6 Resilience

Connectivity is especially important because it likely enhances resilience, as it widens the range of resources on which marine life relies; if one resource is inaccessible, fish can use another (Sheaves, 2009, p. 111). Nicholls and Branson define resilience as "the self-organizing ability of the system to survive and counter change, usually via negative feedback," and suggest that many human efforts focus instead on increasing resistance, which they define as "the ability to stop (or resist) change" (1998, p. 255). They argue that sustainability requires a high level of resilience in order for a system to survive, even in unforeseen conditions and circumstances (Nicholls and Branson, 1998, p. 255). In light of present and predicted stressors on estuaries such as sea level rise, flooding, drought, and increasing acidification (National Estuarine Research Reserve System, 2011), Nicholls and

Branson say that a more holistic approach to conservation including a consideration of the connectivity and interactions between natural subsystems is essential (Nicholls and Branson, 1998, p. 258).

5.0 CONCLUSION

Based on this research, I conclude that each of the three subtidal habitats studied – open-bottom, rocky, and seagrass – is important to different fish types and, therefore, important to the Hinchinbrook Channel Estuary ecosystem as a whole. Siganids were frequently sighted in the rocky habitats but did not feeding there, which suggests that they use rocks for some other purpose like protection. The herbivorous Siganids were seen feeding most in seagrass habitats. On the other hand, Gerres were seen very infrequently in rocky habitats and did not feed there at all. They fed mostly in the seagrass habitats and also a good amount in open-bottom habitats. Planktivores fed most in rocky habitats but also fed frequently in seagrass and open-bottom areas. Site-attached behavior also displayed this pattern, with most of it taking place in rocky habitats, suggesting that these habitats could be of great use to planktivores.

The findings uncovered by this research answers the question posed of "How do herbivores, benthivores, and planktivores utilize open-bottom, rocky, and seagrass estuarine habitats in the Hinchinbrook Channel?" The fact that feeding takes place in all of these habitats can help inform conservation management decisions.

5.1 Management Recommendations

Since all these habitats provide at least some feeding opportunities for fish, all should be conserved in any way possible, with a focus on increasing their resilience. I recommend agricultural reform centered on reduced use of fertilizers and an emphasis on organic practices in the watershed of the Hinchinbrook Channel Estuary. In addition, I recommend stringent fishing limitations on the channel and in surrounding areas connected to the habitats in the estuary. In addition, I recommend a ban on habitat-destructing activities, like bottom trawl fishing and dredging. These regulations should be accompanied by stringent rules on recreational use of the estuary to avoid the disturbance of sea life and the destruction of valuable habitats. In addition, I recommend that Australia and other nations increase reliance on renewable energy resources and decrease dependence on fossil fuels to curb climate change and its substantial impacts on coastal ecosystems around the world.

5.2 Recommendations for Further Study

Further study should analyze the use of other sub-tidal habitats by marine life in the Hinchinbrook Channel Estuary, and should focus on a wide range of specific species to understand the influence of the habitats on each one. Similar studies should be conducted in other estuaries around the world, as estuaries are highly important ecosystems and provide many benefits to humans and surrounding ecosystems. Studies should also be conducted on the connectivity of sub-tidal estuarine ecosystems with other areas, since this could inform further management techniques and provide more insight about their importance. This additional research would also help enlighten scientists and policymakers as to how best to preserve estuarine ecosystems and ensure they remain healthy for generations to come.

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7.0 APPENDICES

7.1 Appendix A: Siganid Feeding Charts

Habitat	Total Cameras	Total feeding	Total not feeding
Open bottom	483	7	9
Rocky	165	4	20
Seagrass	51	3	2

Habitat	Percent Feeding	Percent Not Feeding
Open-bottom	0.014492754	0.01863354
Rocky	0.024242424	0.121212121
Seagrass	0.058823529	0.039215686

7.2 Appendix B: Gerres Feeding Charts

Habitat	Total Cameras	Total Feeding	Total not feeding	Total searching on Benthos
Open bottom	483	23	9	7
Rocky	165	0	2	1
Seagrass	51	14	1	1

Habitat	Percent Feeding	Percent Searching on Benthos	Percent Not Feeding
Open-bottom	0.047619048	0.014492754	0.01863354
Rocky	0	0.006060606	0.012121212
Seagrass	0.274509804	0.019607843	0.019607843

7.3 Appendix C: Planktivore Feeding Chart

Habitat	Total Cameras	Planktivore Feeding	Percent
Open bottom	483	34	0.070393375
Rocky	165	43	0.260606061
Seagrass	51	8	0.156862745

7.4 Appendix D: Movement Behavior Chart

Habitat	Total Cameras	Site attached	Percent
Open bottom	483	22	0.045548654
Rocky	165	15	0.090909091
Seagrass	51	3	0.058823529