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# Foraging ecology and behavior of batoids and their influence on coastal sandflats

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## Abstract

Mesopredators play an important role in many aquatic ecosystems and understanding their behavior and foraging ecology is crucial for maintaining the function and sustainability of these environments. Batoids are specialized benthic predators that act as ecosystem engineers through their foraging behavior which create depressions in the substrate. The process of making these depressions, or pits, disturbs the sediment and cycles nutrients back into the water column, otherwise known as bioturbation (O'Shea 2012).

Using aerial surveys and isotope analysis, this study examined the feeding behavior and feeding pit morphology of two batoid species, *P. ater* and *H. australis*, on a coastal sandflat in northern Queensland. *H. australis* was observed feeding more often (40.19 pits/hour) and used all six feeding combination methods observed (suction feeding, excavation, and type A) compared to *P. ater* which was observed feeding less frequently (15.03 pits/hour) and showing no signs of suction feeding behavior. The size of the pits formed by each species varied with feeding type and feeding activity time; *H. australis* showed high variability in pit size (average ratios of disc width and pit diameter ranging from 0.14 for suction feeding to 0.88 for excavation/type A diameter) with less variance in feeding time (majority <30 seconds length) whereas *P. ater* had opposing results (average pit size ratio range <0.36; activity time majority <120 seconds length). Species were observed feeding in two distinct locations on the sandflat, *H. australis* on the inner sandflat bank and *P. ater* less concentrated on the south-eastern region of the study area. Isotope analysis of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  concentrations showed little difference between species, possibly indicating that *H. australis* and *P. ater* share similar trophic positions, although future studies should incorporate stomach content analysis for a more comprehensive look at diet. Differences in feeding frequency, feeding type and location might suggest that the two species potentially occupy segregated ecological roles on the sandflat. Mechanisms influencing

these results might further be driven by prey preferences and/or resource partitioning between species, which would facilitate the co-existence and reduced competition between the two regionally abundant species. These results might suggest removing either species from the ecosystem would have implications on bioturbation rates and nutrient cycling and should be considered for management and conservation strategies.

*Keywords: batoids, stingrays, foraging ecology, feeding behavior, bioturbation, ecological engineers, stable isotope analysis*

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## Introduction

### *Briefing*

Understanding animal behavior and relationships is of increasing interest to the sustainability of our planet’s resources and ecosystems. Human dependence on natural systems is interlinked with knowledge of biotic and abiotic components that are crucial for overall function and wellbeing of these systems. For example, a study conducted by Myers et. al (2007) found that the decline in abundance of apex sharks over a 35-year period led to an increase in their prey species, in particular cownose rays. Increased predation on bay scallops by cownose rays ultimately led to a century-long decline in the scallop fishery, suggesting a strong presence of cascading effects when top predators are eliminated. The study of animals provides contextualization of the health and resilience of ecosystems, especially in light of a changing climate and growing anthropomorphic stresses. Ecosystem engineers, or species that modify, maintain, or destroy habitat landscapes, particularly impact the relationships and functions of entire systems. Removing these animals from their habitat can have radiating consequences on

biodiversity and dependent human industries, which is why it is important to study these species for the advancement of management and sustainability initiatives.

### *Batoids*

Within the subclass Elasmobranchii, the superorder Batoidea includes skates, stingrays, and sawfish. Batoids occupy a wide range of habitats from the Arctic Circle to the tropics, in both freshwater and saltwater environments (Last and Stevens 2009). Stingrays, sawfish, and skates have convergently evolved the specialized, depressed body shape that is most common amongst chondrichthyans (Aschliman 2011). The unique jaw protrusion characteristic of elasmobranchs offers probable feeding benefits such as increased precision, increased generation of pressure for suction, and expanded procurement of hard to reach prey (Dean & Motta 2004). Because of this combined morphology, batoids have adapted as specialized benthic predators.

Although stingrays occupy a wide range of habitats, they are most commonly found in coastal regions in shallow waters and shelves (O'Shea 2012). In the majority of these ecosystems, rays make up a significant part of the fish biomass (O'Shea 2012), often with high species diversity. Vaudo and Heithaus (2009) hypothesized high species diversity in coastal regions may be due to prey availability, predator avoidance, and behavioral thermoregulation, and could play an important role in shaping nearshore environments. It is also thought that high species diversity is supported in these ecosystems as a result of resource partitioning on both spatial and temporal scales, which may minimize competition (Schoener 1974 in O'Shea 2012).

Because of their foraging behavior, batoids prefer areas with soft sediment such as mangroves, coral reef edges, and sandflats. Batoids are benthic predators, feeding on small

crustaceans and invertebrates in the sand through their free-moving jaw on the ventral side of the body. Ray foraging is a disruptive process, stirring up sediment and creating feeding pits. Pits, or burrows, commonly have two structural characteristics that are caused by different feeding behaviors. The larger, ellipsoidal shape is caused by a gradual flapping of the pectoral fins and rostrum over the sediment surface (Howard *et. al* 1977). The smaller and deeper section of the pit is formed by hydraulic jetting through the gill clefts that pointedly picks out invertebrates buried in the sediment, reaching depths of up to 30 cm (Myrick and Flessa 1996). This behavior and alteration of physical space makes batoids a prime example of an ecosystem engineer. Takeuchi and Tamaki (2014) assumed in their study that the size of feeding pits was directly correlated with the size of the ray, however there is a lack of empirical evidence supporting this relationship.

### *Bioturbation*

Bioturbation is the disturbance of sediments from behavioral processes of living organisms. Batoids are significant sources of habit disturbance due to their foraging behavior which alters physical, chemical, and biological characteristics in an environment (O'Shea 2012). Sediment is overturned, which releases nutrients into the water and redesigns the physical geography of the ecosystem. Organic debris and nutrients collect in the remnant pits which cycles chemicals and resources back into the sediment for sand-dwelling organisms to utilize (O'shea *et. al* 2011). Thrush *et al* (1991) discovered that complete sediment re-working of in an 700 m<sup>2</sup> sandflat would occur within 70 days when a high density of rays was present. Furthermore, they observed a differentiation in burrowing invertebrate distribution when ray pits were present in the area, especially related to recolonization of feeding pits. These pits provide microhabitats on the sandflats and can contribute to overall biodiversity for coastal ecosystems.

Myrick and Flessa's experiment (1995) also concluded high rates of sediment overturn from elasmobranchs on a coastal flat in Mexico ( $0.56 \text{ m}^3/\text{m}^2/\text{year}$ ), showing the substantial capability of habitat disruption from ray behavior. This process of bioturbation is critical to other biological processes and the overall health of an ecosystem (O'Shea 2012) and is strongly linked to the number and size of feeding pits made (Takeuchi and Tamaki 2014). However, not much is known about how feeding behavior, morphology, size of rays, and feeding time correlate with the number and size of pits being made.

#### *Economic Impact and Conservation*

Mesopredators are underrepresented in research as most scientific attention is focused on apex predators. However, mesopredators play an important role in the abundance of both upper level predators as well as intermediate prey within the food chain. They are a crucial link in the health and dynamics of ecosystems, especially when they have a high population presence in a given habitat (Vaudo and Heithaus 2011).

The life history stages of rays operate on a relatively slow scale, with low reproductive rates and late maturity, making them vulnerable to population threats (O'Shea 2012). Bycatch is one of the main threats to batoid populations, especially in the penaeid fisheries (Dell *et. al* 2009 in O'Shea 2012) and benthic trawling fisheries in Australia. However, other parts of the world employ targeted fisheries for stingray; Indonesia captured "105,000 tones and 118,000 tonnes in 2002 and 2003 respectively" making it the largest fishery for stingrays in the world (White *et. al* 2006 in O'Shea 2012). Understanding the roles of batoids is critical to gauge consequences of removing them, and important for long term ecosystem-based management and population health (O'Shea 2012), especially in locations with growing anthropomorphic impacts and direct/indirect fishing pressure.

## *Aims*

Due to the threatened status of batoid populations, it is critical now to understand their roles in marine ecosystems to gauge the consequences of population declines. There is currently a knowledge gap on how different feeding behaviors could affect bioturbation and feeding pit size, which is important for understanding batoids role in ecosystem. The goal of this study was to analyze two sympatric ray species to determine if feeding habits differ and to see if species fulfill similar roles in terms of bioturbation on a coastal sandflat. The study specifically looked at where feeding pits were formed and the influence of feeding time, feeding behavior, species, and ray size on the size of feeding pits on the sandflat. Diets were further investigated to see if feeding locations influenced dietary composition and trophic level of each species through stable isotope analysis.

## **Methods**

### *Study Location & Study Species*

This study was conducted on a coastal sandflat near Lucinda, QLD, Australia. The area of the intertidal sandflat is approximately 2 km wide and extends 1 km seaward at the lowest astronomical tide. The northern boundary of the sandflat is an enclosed bay consisting of a developing mangrove forest and exposed sandflat area. The location experiences a mixed semi-diurnal tidal regime with a maximum tidal range of 4 meters. Eight batoid species have been observed on the sanflat; however, the Cowtail stingray (*Pastinachus ater*) and the Australian whipray (*Himantura australis*) were chosen for this study as they are the most numerically abundant species on the sandflat (Kevin Crook unpublished data).

### *Data Collection*

### Behavior Observations

Individual rays for both study species were tracked using two drone flight methods. Foraging behavior observations were performed using a DJI Phantom 3 Standard Drone. Videos captured by the drone's camera were viewed on an iPad Mini 4 using the application DJI Go. Flights were conducted in the morning at flood, high, and ebb tides before 9:30am due to low winds and minimized influence of glare off the water. Drones were hand-launched from the beach and flown at 10-15 m altitude until a stingray was sighted. Pilots descended to an altitude of 3-5 m above the ray once observed and started video recording. The first tracking method recorded the ray for approximately 20 minutes, as limited by battery life of the drone. The second method involved two drones that track the same ray to extend video recording time up to two hours. When the first drone reached low battery, the second drone was launched above the first until the ray was in view on camera, and the first drone was returned to the launch site. Batteries were changed before each flight and replaced using the same method described above until all batteries were used.

### Seine Net Trapping

Stingrays were caught using a 30 m seine net with a mesh size of 1 cm to collect muscle and blood samples for stable isotope analysis. Researchers waded through sandflat area at intervals of high tide. Rays were encircled by the seine net once spotted and caught using a hand-held net once entrapped. Disc width was measured using a tape measure, and sex of the ray was determined by the presence or absence of claspers (presence of claspers indicates a male). GPS location was recorded at the site of capture. Muscle samples were collected using a 5mm circular biopsy punch and placed in 2mL plastic microcentrifuge tubes. Blood samples were taken from the caudal vein at the base of the tail using a heparinized 5mL syringe fitted with 21 or 23 gauge

needles. Rays were then tagged on the spiracle before release to prevent re-sampling of the same individual. Blood and muscle samples were stored on ice until return to the laboratory.

### *Data Analysis*

#### Video Analysis

Drone videos were analyzed to document and describe stingray foraging behavior. For each video, stingray species, type of feeding behavior, start and end time of each feeding behavior, and if feeding pits were formed during each feeding event were recorded in a spreadsheet. For each video, the rate of pit formation was determined as the number of feeding pits formed divided by the observation time. Three feeding types were identified for the two study species: excavating, suction, and type A feeding. Excavation feeding was defined as the stingray using its pectoral fins and rostrum to loosen sediment for capturing prey. Suction feeding was recorded when rays were observed dispelling of sediment through the spiracles. Type A feeding was defined as the stingray exhibiting minimal movement, with sediment expelling around the disc margins of the ray (Kevin Crook, unpublished data). Screenshots were taken of feeding pits when the full pit was visible and, when possible, the stingray's fins were fully extended in order to measure length of the feeding pit in relation to disc width. Boxes were drawn around feeding pits for identification, as well as for stingrays being tracked when other stingrays were present in the frame. Feeding pit sizes were measured in pixels using ImageJ photo measuring software. Screenshots taken from drone tracking videos were uploaded on the application, using the zoom tool to adjust image so that the pit edges of the pit were clearly visible. The line measure tool was selected, and a line was drawn across the maximum length and width of the feeding pit. Then, the 'measure tool' was selected to record the pixel length for each pit dimension. Ray disc width was measured using the same procedure when the ray's full disc width was clearly visible in the screenshot. Pit size was calculated as a proportion relative to the disc width of the ray by

dividing the pit length/width (in pixels) by the disc width of the ray (in pixels). For each measured pit, the feeding type, feeding duration, and species was recorded.

### *Isotope Analysis*

Stable isotope analysis of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  was conducted using the muscle tissue and plasma samples collected from 10 individuals of each species. Before processing, muscle samples were frozen at  $-20\text{ }^{\circ}\text{C}$  in 2 mL plastic microcentrifuge tubes. To isolate red blood cells from the plasma, blood samples were centrifuged at 7200 rpm for 3 minutes on the day of collection. Muscle samples were dried at  $60\text{ }^{\circ}\text{C}$  for 24-48 hours in a drying oven. Once dry, samples were homogenized using a blunt-ended probe. Plasma samples were also dried at  $60\text{ }^{\circ}\text{C}$  for 2-4 hours after thawing and being placed onto glass microscope slides. Plasma samples were dried for an additional 24-48 hours once transferred from the microscope slides into glass scintillation vials. Using a microbalance, samples were encapsulated in tin capsules and weighed to  $1.0 \pm 2.0\text{ mg}$ . samples were then sent to the University of California- Davis Stable Isotope Facility for analysis using stable isotope ratio mass spectrometer to determine  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , %C and %N. The isotopic signature of  $\delta^{13}\text{C}$  is a measure of the ratio of stable isotopes  $^{13}\text{C} : ^{12}\text{C}$  (per mil, ‰). For nitrogen ( $\delta^{15}\text{N}$ ), the isotopic signature measures the ratio of  $^{15}\text{N} : ^{14}\text{N}$ . (per mil, ‰). Results precision, calculated from standards, was  $\pm 0.05$  to  $0.14\text{‰}$  for  $\delta^{13}\text{C}$  and  $\pm 0.04$  to  $0.11\text{‰}$  for  $\delta^{15}\text{N}$  (SD).

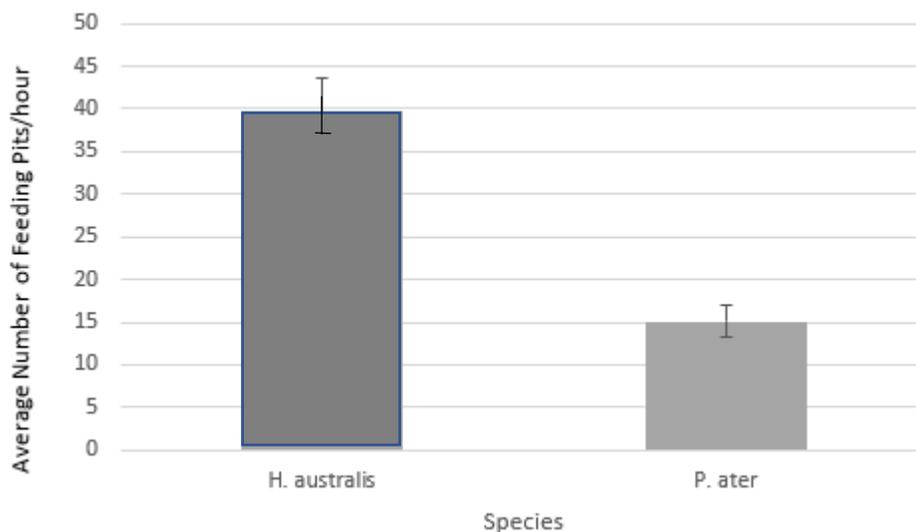
### *Data Visualization*

GPS location was extracted from drone flight logs at the time each feeding pit was recorded on video. Locations were organized in an excel spreadsheet with latitude and longitude coordinates, species, datetime. and activity. The spreadsheet was uploaded into ArcGIS Pro mapping software. Feature classes were created for each species and symbolized by different colored

points to highlight where each species was feeding. Locations were added to the ‘imagery’ base-map.

## Results

*H. australis* and *P. ater* showed differences in the extent of feeding occurrences as well as location of feeding events recorded. *H. australis* was observed more times feeding than *P. ater*, with an average of  $40.19 \pm 3.39$  (SE) pits made per hour compared to  $15.03 \pm 2.13$  (SE) pits per hour, respectively (**Figure 1**). Both species on average were observed feeding most often during flooding tide (period when the tide is moving in towards shore) and least often at ebbing tide (when the tide is flowing out from the coast).



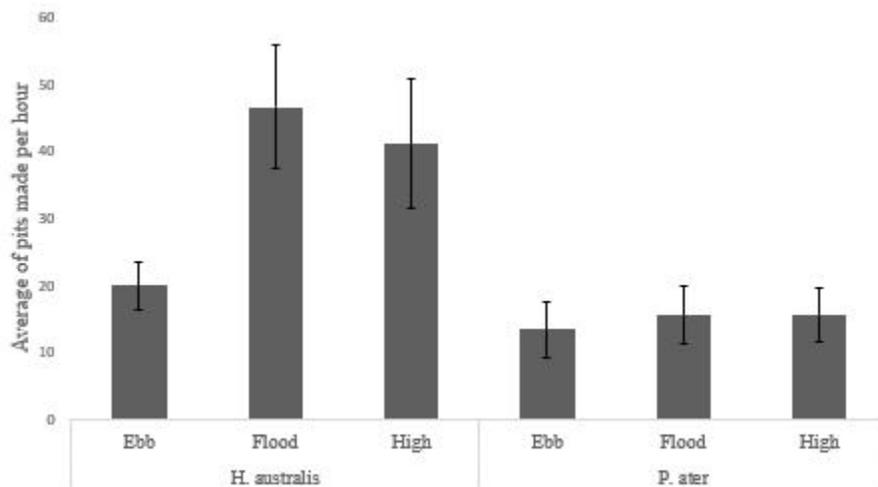
**Figure 1.** average number of feeding pits made per hour for both species *H. australis* and *P. ater*. Error bars represent standard error.

*H. australis* generally fed in a precise, condensed area of the sandflat along the shoreline. In contrast, *P. ater*'s feeding locations occupied a broader area, with a similar trend of pits made along the inner stretch of the sandflat (**Figure 2**). It is evident that the two species were observed

feeding in different locations on the area of sandflat studied. Feeding patterns were analyzed in comparison to the tidal cycle, particularly at phases of high tide. There was minimal difference in the occurrence of feeding events observed between tidal phases for *P. ater* as the average number of pits made per hour for each phase were between 16-13 pits/hour. *H. australis* showed more variability in feeding in relation to the tides, as only  $19.98 \pm 3.63$  (SE) pits/hour were made at ebbing tide, compared to  $46.62 \pm 9.13$  (SE) at flooding tide and  $41.08 \pm 9.62$  (SE) at slack high tide (Figure 3).

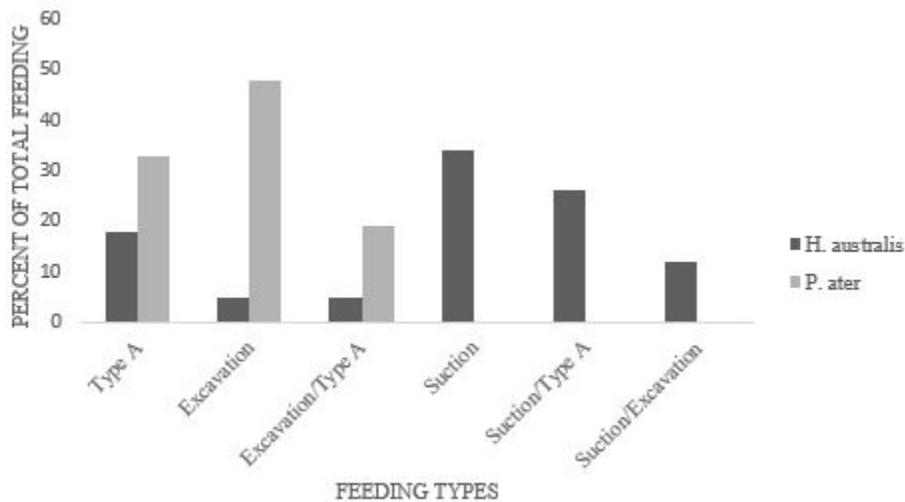


**Figure 2.** Map of Lucinda sandflat showing the locations of feeding pits made by *H. australis* and *P. ater*. The **red** represents pits made by *H. australis* and the **yellow** represents pits made by *P. ater*.



**Figure 3.** average number of feeding pits made per hour during each tidal phase by species *H. australis* and *P. ater*. Error bars represent standard error.

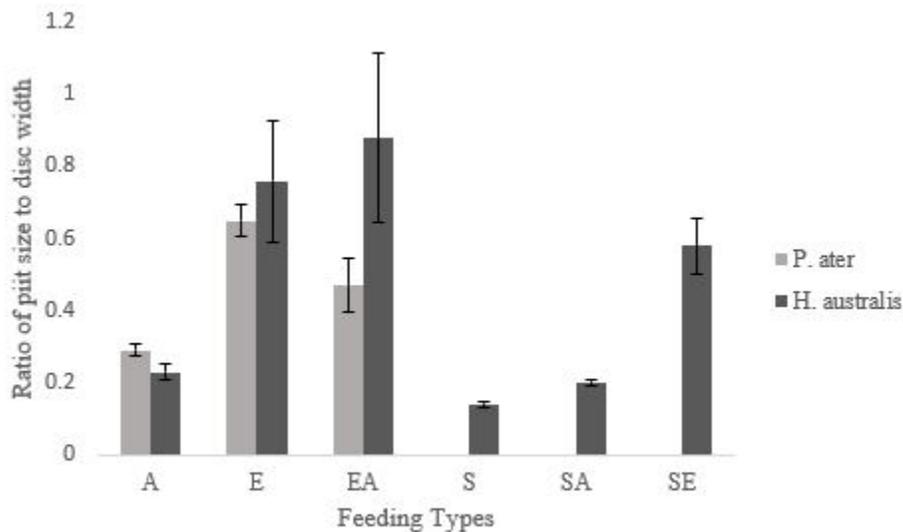
The frequency of feeding behaviors for *H. australis* and *P. ater* varied considerably between species. *H. australis* exhibited six different feeding types that included three main categories- excavation, suction, and type A, as well as combinations of these types- excavation/type A, suction/type A and suction/excavation. Suction feeding made up 34% of feeding observations for *H. australis*, followed by suction/type A at 26%, and type A at 18%. In contrast, *P. ater* only exhibited feeding types of Type A, excavation, and Excavation/Type A, with no indication of suction feeding behavior. Excavation was the most common behavior observed for *P. ater*, comprising 48% of total feeding behavior for this species (**Figure 4**).



**Figure 4.** the percent of total time spent performing each feeding type for *H. australis* and *P. ater*.

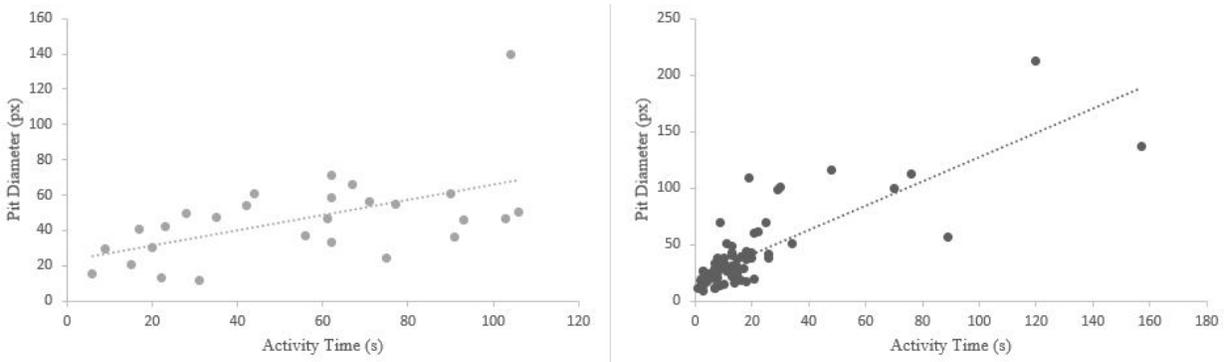
In addition to activity time, feeding type also influenced feeding pit size (**Figure 5**). Excavation feeding types correlated with a larger average pit size compared to other feeding types. Excavation/Type A feeding by *H. australis* produced the largest ratio of pit diameter to disc width at  $0.88 \pm 0.24$  (SE), although the same feeding type exerted by *P. ater* produced much smaller pits on average ( $0.47 \pm 0.07$  (SE)). The smallest pit ratio,  $0.14 \pm 0.01$  (SE) was also made

by *H. australis* when suction feeding was used. Excavation feeding was both the most frequented feeding behavior of *P. ater* and also produced the largest pits at an average ratio of  $0.65 \pm 0.05$  (SE) (still smaller than *H. australis*). Type A associated feeding behaviors appeared to be less commonly used by both species and produced relatively small pit sizes averaged  $<0.26 \pm 0.02$  (SE) each. The lower observed frequency for Type A could also be due to the ambiguous nature of this feeding type and its difficulty identifying it as such.



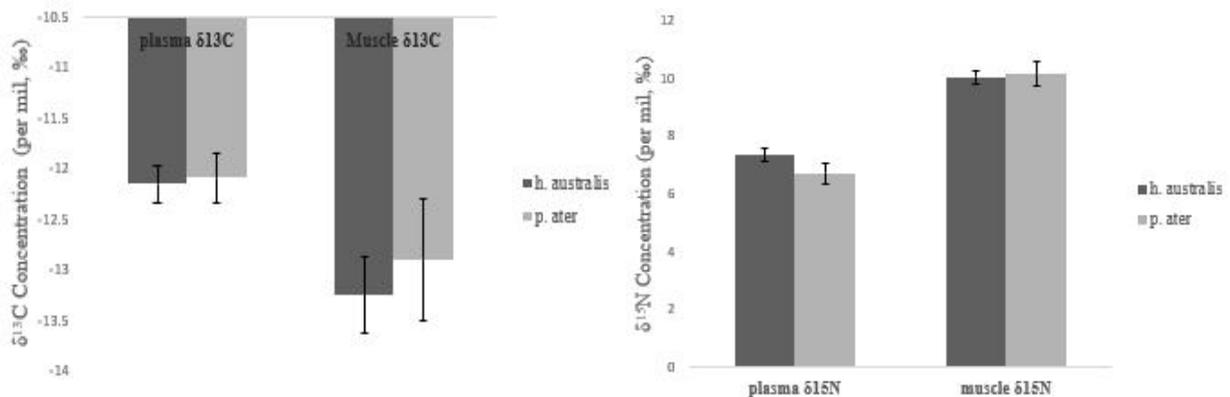
**Figure 5.** feeding behavior types in relation to average pit diameter (px) for *H. australis* and *P. ater*. Feeding types were abbreviated as the following: A= Type A; E= Excavation; EA= Combination of Excavation/Type A; S= Suction; SA= Combination of Suction/Type A; SE= Combination of Suction/Excavation. Error bars represent standard error.

As shown in **Figure 6**, feeding activity time is likely highly correlated with the size of feeding pits made. In general, larger pits were made when activity time was longer for both species. However, *P. ater*'s activity time was more evenly distributed and consisted of more time-intensive feeding events compared to *H. australis*, who more frequently foraged for shorter durations. *P. ater* was observed feeding less often than *H. australis*, explaining the smaller sample size for this species (27 for *P. ater*; 80 for *H. australis*) (**Figure 1**).



**Figure 6.** feeding activity time (s) in relation to pit diameter (px) for *P. ater* (left) and *H. australis* including line of best fit.

Results from the stable isotope analysis showed little difference in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  concentrations between the two species, *H. australis* and *P. ater*. The average of plasma  $\delta^{13}\text{C}$  for *H. australis* was  $-12.16 \pm 0.18$  (SE) and  $-12.10 \pm 0.25$  (SE) for *P. ater*, and the average muscle  $\delta^{13}\text{C}$  concentrations were  $-13.25 \pm 0.38$  (SE) and  $-12.90 \pm 0.61$  (SE), respectively (**Figure 7**). Average  $\delta^{15}\text{N}$  concentrations in the plasma and muscle samples of *H. australis* were  $7.32 \pm 0.22$  (SE) and  $10.02 \pm 0.26$  (SE) respectively, and for *P. ater* were  $6.69 \pm 0.33$  (SE) and  $10.13 \pm 0.42$  (SE), in order (**Figure 7**).



**Figure 7.** isotope analysis results quantified by abundance of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  for *H. australis* and *P. ater*, respectively. Values are shown for muscle and plasma samples collected for both species. Error bars represent standard error.

## Discussion

Results showed that *H. australis* feed more frequently than *P. ater*, which could be connected to their longer observed feeding activity time and/or more efficient predation rates. The two species seem to exhibit different feeding behavior in different locations on the sandflat possibly due to a difference in prey type or resource partitioning. The size of feeding pits created by *H. australis* and *P. ater* appear to be influenced by activity time and feeding type which could suggest variance in bioturbation and nutrient cycling based on these factors.

*H. australis* was clearly observed feeding more often than *P. ater*, and therefore had a larger sample size for analysis. The low frequency of feeding events for *P. ater* might be the result of it feeding for longer, on average, so they are not making as many pits in the process. Many behavioral observations made for *P. ater* were dominated by travelling and resting behaviors rather than feeding. One hypothesis to explain this might be that *P. ater* feeds more at a different time of day rather than the morning; developing a way to survey ray behavior in the evenings would be able to test this hypothesis. The tidal phases likely influenced when rays were feeding as few of either species were observed feeding during ebbing tide when compared to flooding and high tide phases. When water is flowing out from the sandflat at ebbing tide, there is a greater risk of being stranded, and therefore less feeding activity at this time. Generally, most rays seemed to spend their time in the intertidal zone and migrated deeper when the tide was going out.

The size of feeding pits for both *P. ater* and *H. australis* appears to be influenced by two main factors: feeding behavior type and feeding activity time. Excavation feeding types have a much greater average pit size than type A and suction feeding types. The strategy of excavation feeding might allow the stingray to access prey deeper in the sediment, which in the process

creates large depressions. Because of this feeding mechanism, disc width, in particular for excavation feeding, might associate with the size of the pit. Theoretically, as disc width increases, the size of the pit proportionately increases as well with excavation feeding types, but further study of this concept should be conducted to make any firm conclusions. Suction feeding, on the other hand, appears to involve less full body mechanics and typically makes the smallest feeding pits out of the behaviors observed. This type of feeding possibly is used as a more precise pathway for picking out prey.

*P. ater* was not observed using suction feeding during the study, and instead utilized excavation feeding most often. Based on the findings stated above, *P. ater* would be thought to have a potentially higher rate of bioturbation, however the size of their excavation pits was smaller than those created by *H. australis* and therefore not overturning as much sediment. *H. australis* seems to create a larger variety of pit sizes but also produced larger pits on average than the *P. ater* during excavation feeding. Type A feeding was the most ambiguous and most difficult feeding type to identify, but because it still produced feeding pits, prospective bioturbation differences between species would be minimal due to the similarity in observed frequency of this behavior. It is apparent that there are complicated dynamics with regards to bioturbation, although there is evidence that rates of bioturbation might relate to prey density. Takeuchi and Tamaki (2014) found an interesting correlation between feeding pit size and density of prey, in that larger pits were commonly found in areas with relatively low prey density, and smaller pits were found more abundantly in moderate-high prey density areas. Despite the complexities observed in the distribution of feeding pit size amongst species, perhaps further analysis of infaunal organism density and location, similar to Takeuchi and Tamaki's study, can help predict bioturbation rates on a spatial scale for each species. Overall, the results

support the idea that *H. australis* and *P. ater* exhibit different feeding behaviors and therefore likely influence nutrient cycling differently.

Feeding activity time seems to also play a role in the size of pits made by both species. There seems to be a positive linear correlation with feeding time and the size of feeding pits, as an increase in feeding time generally equates to an increase in the size of the pit. Some speculation as to why rays spend more time feeding in certain locations revolves around the success of predation, and the abundance of prey. Feeding events that are longer could be a result of more food in that spot, so the rays concentrate their efforts for longer. Alternatively, the density of prey could be low in that area and/or harder to capture which would require more effort and time spent. Excavation feeding seemed to have the highest feeding time of all the feeding types, either due to more complex physical mechanics of this behavior or because it simply requires more time to complete. *P. ater* evidently spends more time in each feeding event than *H. australis*, which would coincide with its dominant use of excavation feeding.

It could be speculated that suction feeding is associated with catching a certain prey type that *P. ater* is not feeding on, and therefore might explain why they are not exhibiting this behavior. Conjointly, the separation of feeding locations could also possibly support the idea that the two species might be feeding on different prey. Dean, Bizzaro and Summers (2007) found associations between dietary and morphological characters stating that certain physical mechanisms predict different diets. *H. australis* and *P. ater* could have variability in feeding morphology which would further support the idea they are feeding on different prey; future research on the anatomy of these species would be needed to confirm or refute this hypothesis. Stomach content analysis would also help investigate dietary composition further, which is elaborated on later.

*H. australis* and *P. ater* were observed using different parts of the sandflat. One cause for this distribution of feeding spots might be the existence of sediment types that are preferentially unique for the two species. Alternatively, spatial niche partitioning between the species could explain the different feeding locations, which would simultaneously allow coexistence of species and minimize competition for food. As previously mentioned, this niche partitioning might further be driven by different prey preferences affecting spatial distribution. This presumable conclusion was established by several other studies including Plattel, Potter and Clarke (1998) who stated that the coexistence of batoid species on a south-western Australian sandflat was likely supported by the partial segregation of the four species sampled, as well as the dietary composition and differences in feeding habits. Another study by Bornatowski et. al (2014) also identified resource partitioning of four batoid species in southern Brazil, where the species consisted of different diets while sharing the same space. The difference in isotope values was very little, which might suggest that the species occupy the same trophic positions, however isotope analysis does not always provide a comprehensive look at diet. Vaudo and Heithaus (2011) found that although isotope values were similar amongst the species surveyed, the stomach contents of *Pastinachus atrus* showed a difference in prey types compared to other species, suggesting the limitations of isotope analysis for dietary composition. Although isotopic analysis offers a more stable look at the foraging habits of an organism by “reflecting the assimilated material” (Vaudo and Heithaus 2011) over time, research that incorporates stomach content analysis in conjunction with isotope analysis would offer a more complete look at diet.

There were several limitations to the study that should be addressed. Drone flights used for aerial surveys of rays was constrained to the morning due to the weather and glare limits for drone functions, which could have influenced the accuracy of behavioral observations as the

whole day was not surveyed. Additionally, the water was too deep in sections of the sandflat to conduct drone surveys, which limited the study to specific areas of the flat that might not represent the location as a whole. All stingrays in the area surveyed were juveniles, meaning data collection and interpretation is representative only for the juvenile populations of the species.

There are several factors that lead the study to conclude that *H. australis* and *P. ater* are likely occupying different roles on the sandflat due to differences in feeding behavior and time, feeding locations, and average pit sizes. The two species possibly produce different rates of bioturbation as *P. ater* did not exhibit any suction feeding behavior and made fewer pits than *H. australis*. In contrast, *H. australis* made more pits and used a greater variety of feeding habits. Furthermore, the species were found feeding in separate locations on the sandflat, therefore impacting varying zones in the area. Because of these differences, *H. australis* and *P. ater* presumably turn over sediment in different quantities and locations, which is important for bioturbation and ecosystem engineering. Should one species be removed from the sandflat, there would be predictable implications on other processes in the ecosystem. Using the findings from studies such as Myrick and Flessa (1996) in conjunction with our study of pit size in relation to feeding time, type, and species will help provide critical knowledge for management and preservation improvements of sandflat ecosystems. Future studies might consider looking at the following: stomach contents for a more in-depth review of diet, conducting benthic organism surveys to find what possible prey types are available in the area, quantifying the amount of sediment turned over by each species and the abundance of species, or incorporating AI for more large scale surveys and coastal mapping.

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