

## **Efficacy of Marine Protected Areas for seabird species richness and abundance**

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## Abstract

Seabirds, or birds that are affiliated with the marine environment, are important intertidal predators whose effects due to anthropogenic impacts may reflect the environment in which they inhabit. In this way, seabirds may be considered indicator species, or species that directly signal shifts in the health of their associated ecosystem. Marine lagoons, which support diverse benthic communities, are an example of an ecosystem in which seabirds act as indicator species. Despite the designation of Marine Protected Areas (MPAs) for some lagoons on San Juan Island, WA, the benefits of this strategy for highly mobile species, such as seabirds, must be better understood for the conservation of seabirds. The present study was an observational study designed to test whether seabird species diversity at the MPA, Argyle Lagoon, is greater than that of the unprotected lagoon, Third Lagoon. Similarly, the present study attempted to test whether the species diversity of seabird prey is greater at the protected lagoon relative to the unprotected lagoon. Two counts were performed in the morning and the afternoon at each site, with seabird identification and count being recorded. Sediment samples were also taken at each site once a day, using mesh sieves, and noting observed prey individual and group count. One tailed t-tests were then performed to determine significance of the relationships of seabird and prey diversity against protectiveness. Seabird richness, the number of unique species, and abundance, the number of individuals, was significantly greater at the protected lagoon than at the unprotected lagoon. Prey richness and abundance was similarly increased at the protected lagoon relative to the unprotected lagoon, but the relationship between prey and protectiveness was not significant. While the designation of MPA for Argyle Lagoon may have explained the substantially increased species diversity of both seabird and prey species, a more likely explanation is the continuous inflow of seawater creating a more rich, diverse, and appealing ecosystem for seabirds and associated prey species at Argyle Lagoon compared to Third Lagoon.

## Introduction

Seabirds, or any bird that frequently utilizes the marine environment, play important roles as intertidal predators as well as have immense and direct effects due to anthropogenic impacts (Parsons et al. 2008). Seabirds are prime examples of indicator species, which are species tightly interwoven with biological processes, meaning any changes they experience may be reflected in the health of their associated food webs (Miller et al. 1998/1999). These changes include shifts in population abundance, species richness, growth rate, fecundity, and sex ratio (Siddig et al. 2016). In an ever-changing world, indicator species have become essential to understanding shifts in an ecosystem.

More specifically, seabirds act as an indicator species in marine lagoons, which are bodies of water separated from larger bodies of water by narrow stretches of land (Allaby 1990). Because of the sheltered nature of these environments, marine lagoons support diverse benthic communities, making lagoons essential feeding grounds for seabirds (Mendonça et al. 2007). When occurring in high densities, seabird predation on invertebrates in marine lagoons may contribute immensely to the species composition of benthic communities, consequently affecting the entire food web (Mendonça et al. 2007). The species diversity of seabirds and prey should therefore be representative of the lagoon's ability to support the ecosystem (Parsons et al. 2008).

Marine Protected Areas (MPAs) are one method of managing species that are especially susceptible to changes to their environment by designating areas of protection by which anthropogenic stressors may be limited (Dudley 2008). However, the efficacy of MPAs for seabirds has been debated seeing as seabirds have been found to require protective measures at

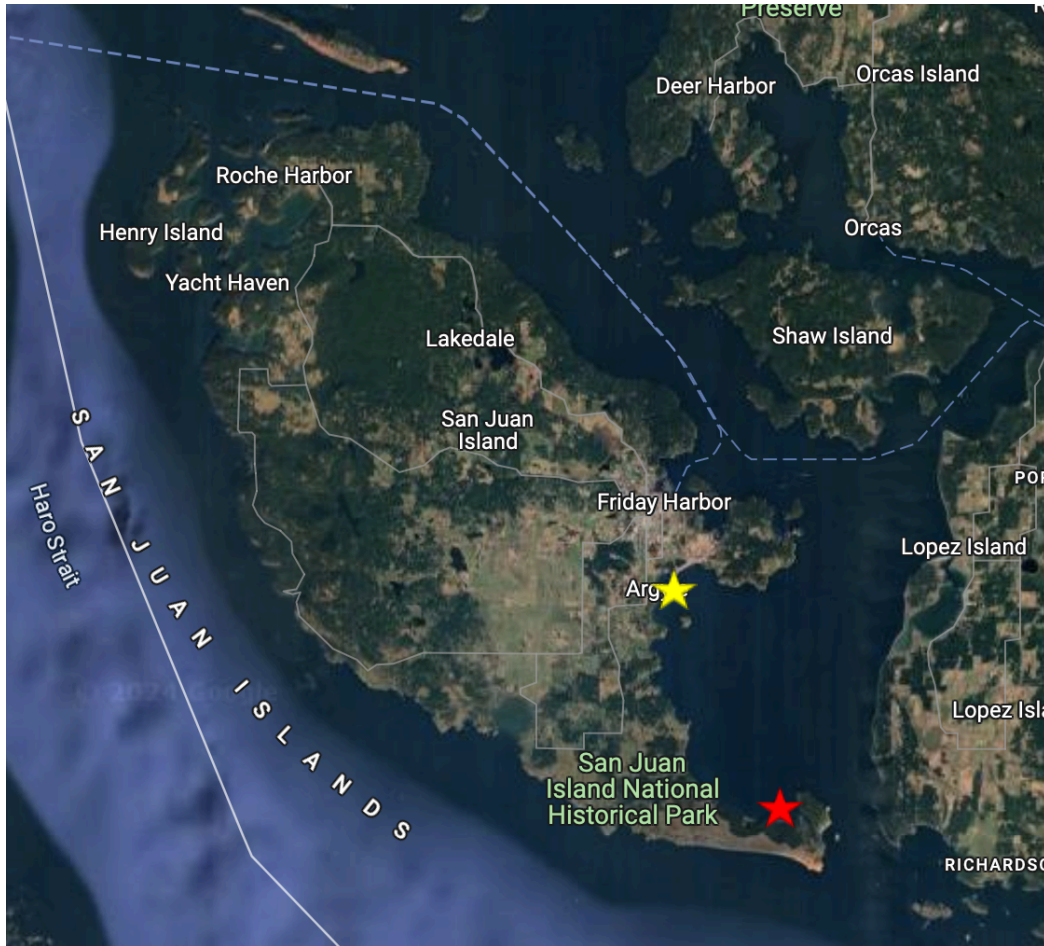
large spatial scales as they are highly mobile (Yorio 2009). On San Juan Island, WA, where this study took place, there has been little research done on how designated marine protected lagoons affected seabird populations. Due to their important ecological role and their vulnerability to changing environmental conditions, understanding the extent to which seabirds benefit from MPAs, specifically in marine lagoons, is crucial for conservation purposes.

In this study, the species composition and abundance of seabirds and their associated prey groups at two lagoons, one protected and one unprotected, was observed. The present study was designed to test whether seabird species diversity at the protected lagoon is greater than that of the unprotected lagoon. Similarly, the present study attempted to test whether the species diversity of seabird prey was greater at the protected lagoon relative to the unprotected lagoon.

## **Methods**

### *Study Sites*

Two sites on San Juan Island, Washington, USA were chosen for this study: Argyle Lagoon Marine Preserve (48.521036, -123.011834), an MPA as of 1990 associated with the University of Washington, and Third Lagoon (48.461307, -122.975823), an unprotected marine lagoon (Figure 1). To avoid any confounding variables impacting the results, the sites were selected for their several shared characteristics: both were marine, had similar surrounding vegetation, and were protected from wave action. The lagoons differed in size with Argyle Lagoon being approximately 0.05 km<sup>2</sup> and Third Lagoon at 0.01 km<sup>2</sup> and water inflow with Argyle receiving consistent water inflow from Argyle Creek. These lagoons were the most similar marine lagoon habitats on the island that also had different protection designations, despite size and water inflow differences. The sizes of the lagoons were determined using the DaftLogic Area Calculator tool.



A



**Figure 1.** Map of San Juan Island highlighting location of Argyle Lagoon, yellow, and Third Lagoon, red (A). Map of Argyle Lagoon showing vantage point (B). Map of Third Lagoon showing vantage point (C).

### *Seabird Count*

This study was carried out over seven, nonconsecutive days between May 3rd and May 24th of 2024, with data collection occurring in the morning and the afternoon to control for tidal differences. Birds were recorded if they were present in the boundary zone at the time of

counting and identification (Table 1). At both Argyle and Third Lagoon, the boundary zone included the lagoon as well as the surrounding shore. Old Town Lagoon represented the unprotected lagoon for the first three days of data collection until Third Lagoon was deemed a more appropriate lagoon for the purposes of this study. The seabird species count and abundance of Old Town Lagoon were included in the dataset but were not used in statistical testing. Birds were counted and identified using Vortex Diamondback HD binoculars or a 10x42 magnification Celestron Ultima 80 spotting scope if the birds were too far away to be identified with the binoculars. While standing at the vantage points outlined in Figure 1, an initial count and identification of every bird within the boundary zone occurred by scanning from left to right. The count did not occur within a specific time frame but ended after each bird was identified and counted. After this initial count, a final count occurred ten to fifteen minutes later. This interval was done to ensure birds had the chance to leave or enter the boundary area, in theory meaning the second survey would be of different individuals. Data was collected in a field notebook and then added to a Google Spreadsheet. To avoid error from recounting, seabird abundance and species counts were then averaged per day. This entire survey procedure was repeated at the second site.

### *Sediment Samples*

At both lagoons, six sediment samples were taken per day to gather a count of prey groups and abundance (Table 2). Samples were taken from just above where the sand meets the water with sites for sampling chosen randomly each day, assuming the six samples would create a representative sample set of the prey composition at each lagoon. Using a shovel, ~5 cm of sediment was dug up and put through a 2mm, USA standard mesh test sieve. The value of 5cm was chosen to reflect the greater yellowlegs bill, which was the seabird with the longest bill that could be seen during this survey. Sediment in sieves was strained in the water by gentle shaking which filtered out sediment and targeted invertebrates visible to the naked eye. Organisms were then counted and categorized by morphology into worms, crabs, bivalves, amphipods, bubble snails, anemones, beetles, and snails, which were any snails that were not bubble snails. Counting and general identification of prey groups was then recorded in a field notebook and then added to a Google Spreadsheet (Table 2). As was done for the seabird data, prey abundance and group counts were averaged per day.

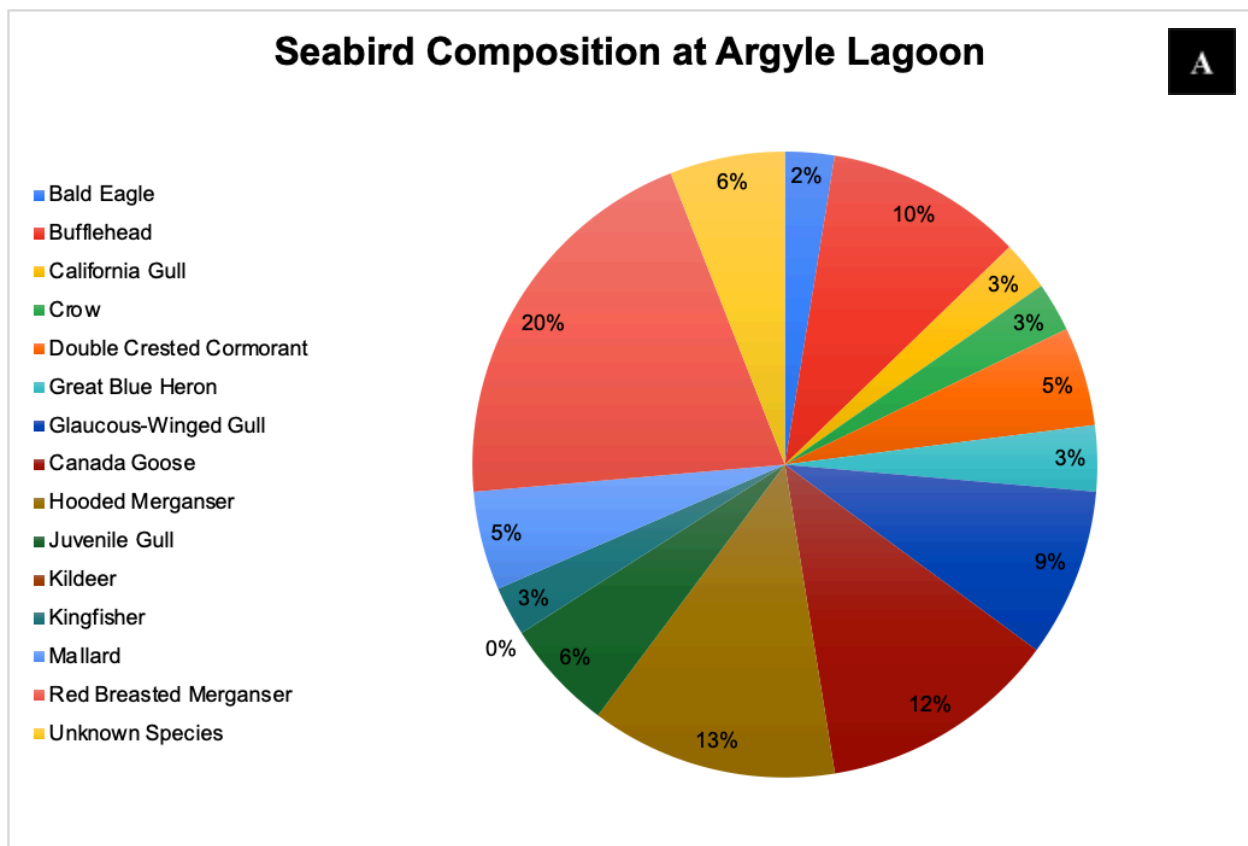
### *Data Analysis*

One tailed t-tests of unequal variance were performed in Excel to test the significance of the relationship between species diversity of seabirds and prey groups with protectiveness of the site. T-tests were the appropriate statistical testing method because the means of two groups of data was compared to determine a relationship between them (Kim 2015). The first t-test compared the quantitative category of daily seabird count with the qualitative category of protectiveness, meaning the seabird abundance at the Argyle Lagoon vs Third Lagoon. The second t-test compared the amount of seabird species counted each day with protectiveness. Two more t-tests were performed: one with prey group count vs protectiveness and the other with prey abundance vs protectiveness.

## **Results**

As expected, Argyle Lagoon exhibited an overall higher average seabird abundance and species count compared to Third Lagoon and Old Town Lagoon, as well as a far more diverse

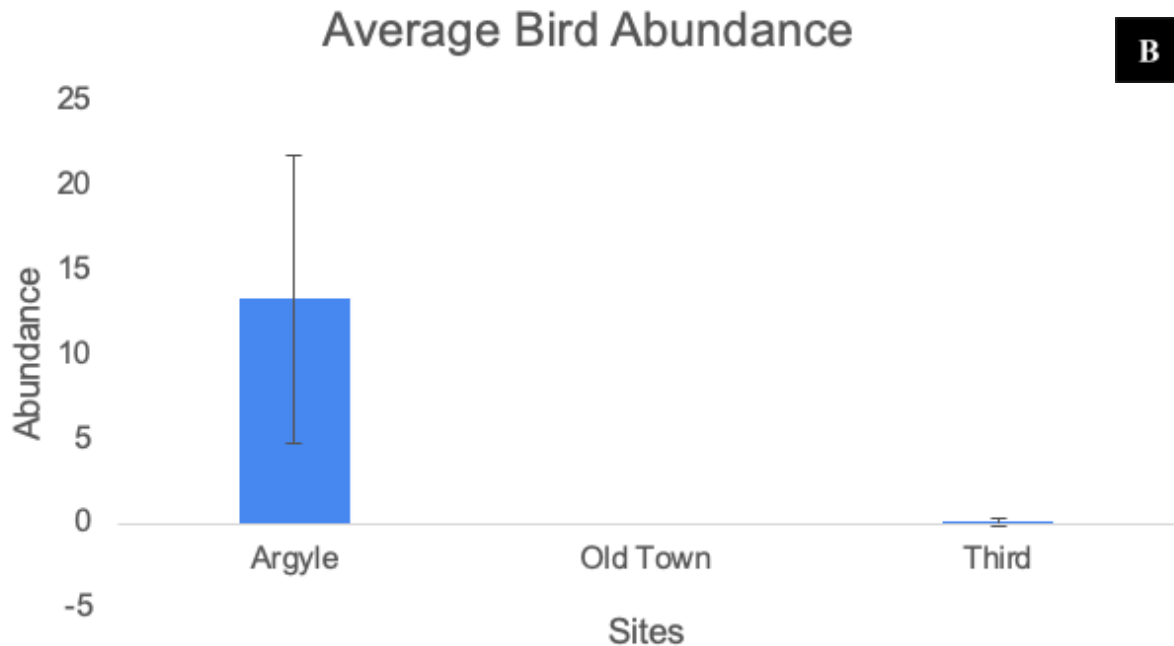
species composition. At Argyle Lagoon, 14 species were successfully identified throughout the survey (Figure 2). The most frequently recorded species were red breasted mergansers at 20%, hooded mergansers at 13%, and canadian geese at 12%, followed closely by buffleheads at 10% and glaucous-winged gulls at 9%. The average number of seabird species recorded per day at Argyle Lagoon was 4.05 species with a standard deviation of  $\pm 1.67$  (Figure 3A). The total count of seabirds recorded at Argyle Lagoon ranged from 2 birds per day to 37 birds per day, with the average number of seabirds counted daily at Argyle Lagoon being 13.4 birds at a standard deviation of  $\pm 8.88$  (Figure 3B). Compared to Argyle Lagoon, only one seabird, a killdeer, was spotted in the boundary zone of Third Lagoon throughout the duration of the survey (Figure 3). An average of 0.05 species were counted as well as an average of 0.05 individuals counted daily, both with a standard deviation of  $\pm 0.22$ . The relationships between protectiveness and seabird species abundance (one-tailed t-test,  $t = 6.76$ ,  $p < 0.05$ ) and protectiveness and seabird species richness (one-tailed t-test,  $t = 10.7$ ,  $p < 0.05$ ) were significant. No seabirds were seen at Old Lagoon, leaving an average seabird species count and abundance at a daily average of 0 (Figure 3).





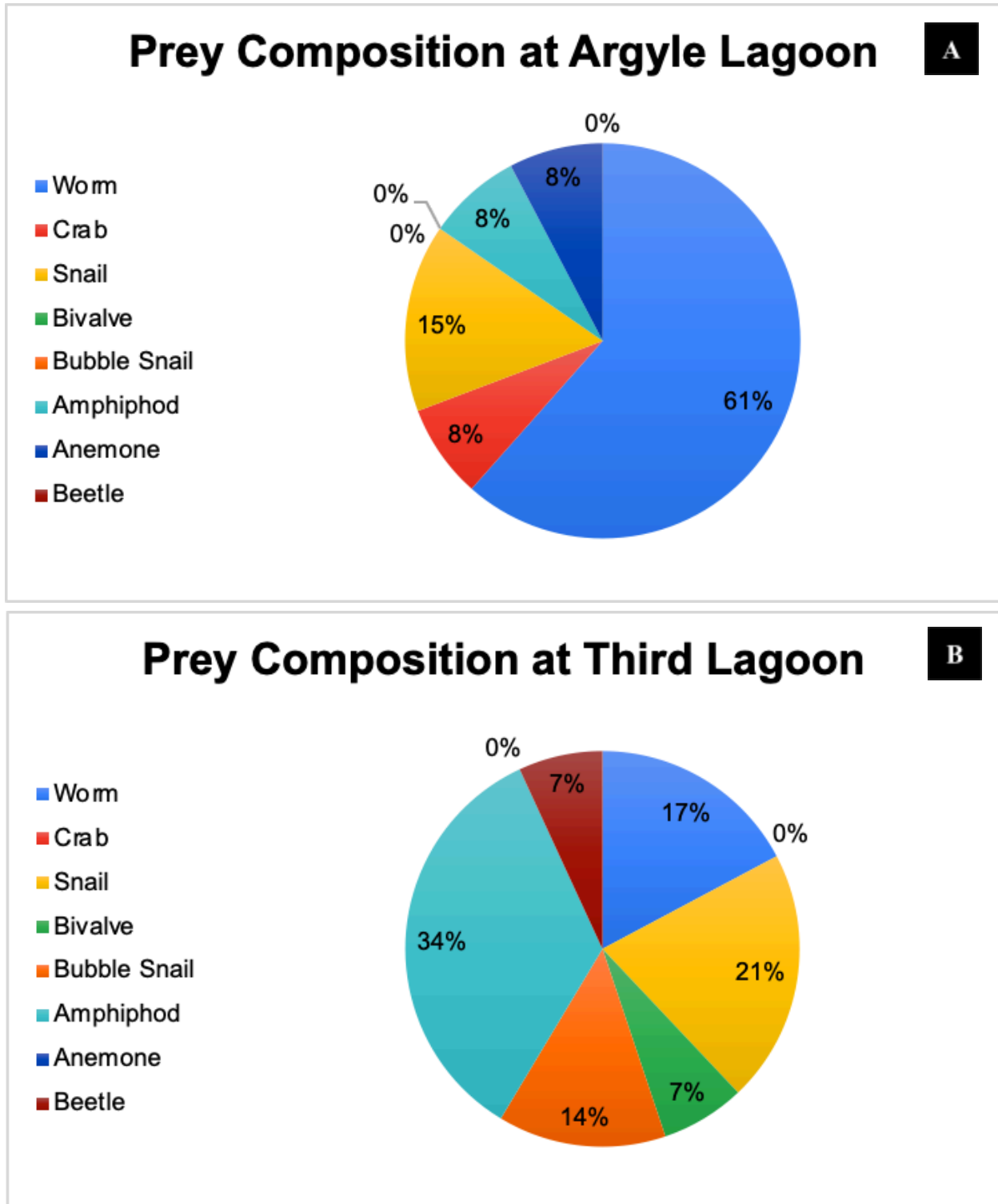
**Figure 2.** Pie chart of observed seabird composition at Argyle Lagoon (A). Pie chart of observed seabird composition at Third Lagoon (B).



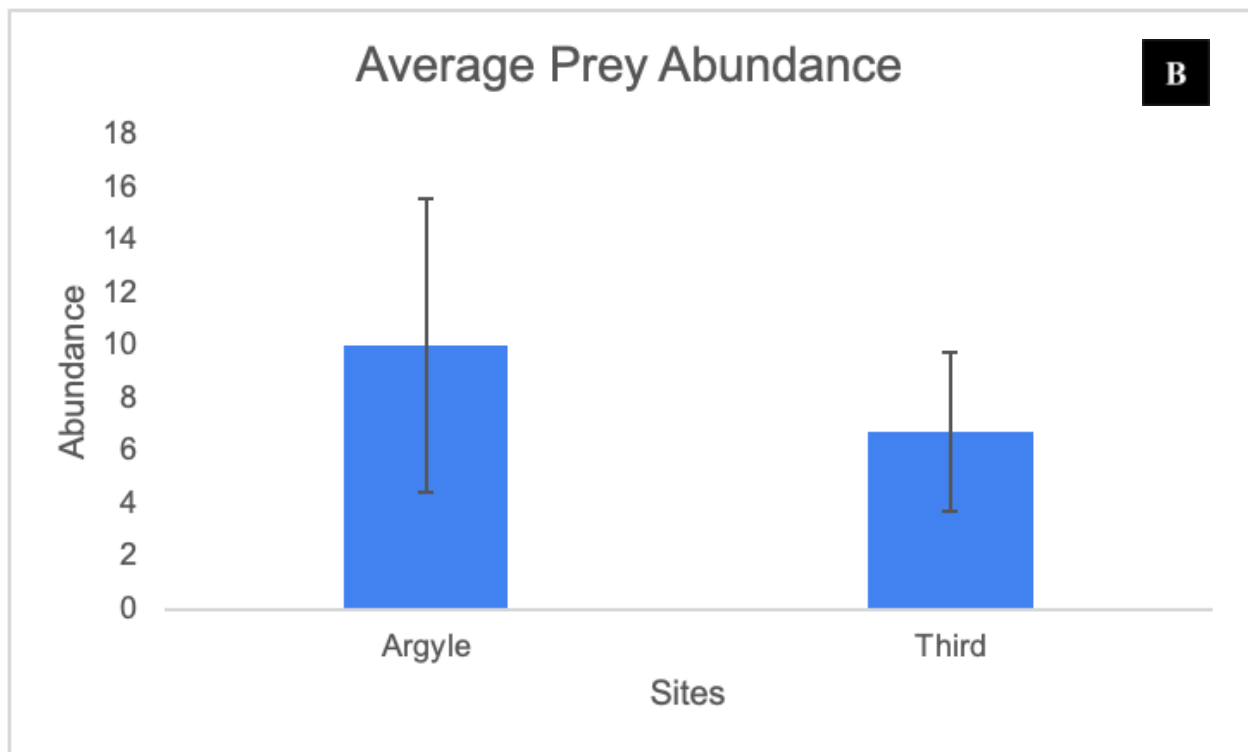
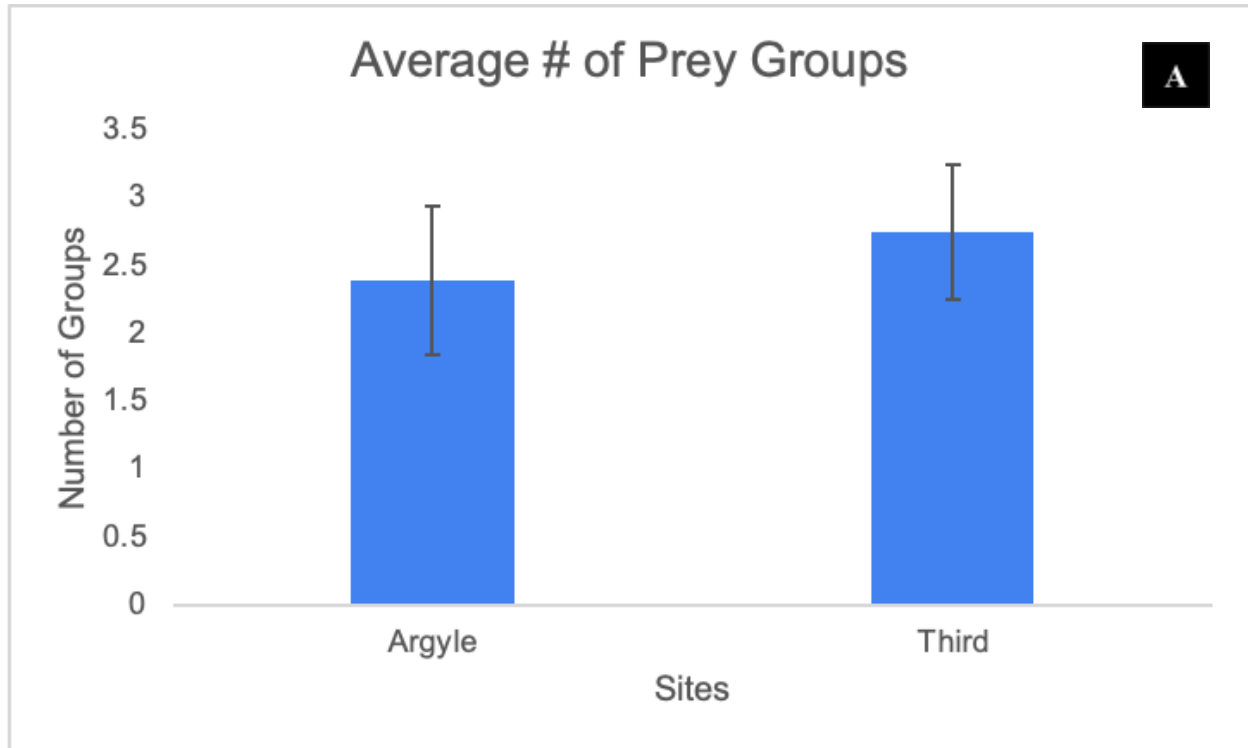


**Figure 3.** Bar plot showing the daily average number of seabird species at Argyle vs Old Town Lagoon vs Third Lagoon (A). Bar plot showing the daily average seabird abundance at Argyle vs Old Town Lagoon vs Third Lagoon (B).

Both lagoons featured different invertebrate compositions with Third Lagoon having overall more prey groups counted but a lower prey abundance compared to Argyle Lagoon. This was different from the stated hypothesis that the protected lagoon would exhibit both increased abundance and species richness. At Argyle Lagoon, the prey groups found were dominated by worms at a 61% frequency followed by snails at 15% (Figure 4A). The Third Lagoon prey composition was more even with amphipods being the most frequent at 34%, with snails close behind at 21% (Figure 4B). Third Lagoon had a slightly higher average number of prey groups, 2.75, with a standard deviation of  $\pm 0.50$ , in comparison to Argyle Lagoon with a slightly lower average number of prey groups, at 2.40 with a standard deviation of  $\pm 0.55$  (Figure 5A). However, Argyle Lagoon exhibited an increased average prey abundance at 10 individuals per day with a standard deviation of  $\pm 5.57$  with Third Lagoon at an average of 7 individuals per day with a standard deviation of  $\pm 3.16$  (Figure 5B). The relationships between protectiveness and prey abundance (one-tailed t-test,  $t = 1.02$ ,  $p > 0.05$ ) and protectiveness and prey group diversity (one-tailed t-test,  $t = -1$ ,  $p > 0.05$ ) were nonsignificant.



**Figure 4.** Pie chart with observed prey group composition at Argyle Lagoon (A). Pie chart with observed prey group composition at Third Lagoon (B).



**Figure 5.** Bar plot showing the daily average number of prey groups at Argyle vs Third Lagoon (A). Bar plot showing the daily average prey abundance at Argyle vs Third Lagoon (B).

## Discussion

Argyle Lagoon overall had a higher average seabird abundance and species count relative to Third Lagoon as well as significant p-values associated with protectiveness and seabird species count and protectiveness and seabird abundance. This supports the hypothesis that seabird species diversity at the protected lagoon would be greater than that of the unprotected lagoon. This may be due to the designation of the MPA at Argyle Lagoon. MPAs have been observed to successfully protect seabird nesting habitats by encouraging less human disturbance or habitat modification (Yorio 2009, Gilmour et al. 2022). However, despite the protection of some critical habitats, stationary MPAs may not be entirely effective for seabirds that have large ranges or migratory patterns reaching outside of MPAs (Gilmour et al. 2022). A potential conservation-related solution to account for highly mobile species is implementing a mobile MPA that changes according to spatial and temporal dynamics (Gilmour et al. 2022, Maxwell et al. 2015). This may include the establishment of multiple MPAs to account for several different habitats used by seabirds or may mean using a dynamic management approach: predicting responses of seabirds to environmental changes and designating MPAs for shorter periods of time depending on what is needed by the species (Gilmour et al. 2022, Maxwell et al. 2015).

The hypothesized relationship between prey diversity and protectiveness was not supported seeing as Third Lagoon had a higher species richness but a lower abundance compared to Argyle Lagoon (Figure 5). The differences between prey group composition and species count between each lagoon may be due to the amount of water inflow each lagoon receives. Argyle Lagoon is directly connected to seawater via Argyle Creek which funnels water into the lagoon during high tide. Higher hydrodynamic activity is associated with increased organic matter supporting more primary productivity and therefore more diverse and abundant invertebrates (Witbaard et al. 2001, Snelgrove and Butman 1994). Because of this continuous input of water, the sediment of Argyle Lagoon is more porous and sandy in comparison to the dense, clay-like texture of the sediment at Third Lagoon, both which may support species with different feeding strategies (Wieking and Kröncke 2005). On the other hand, Third Lagoon is most likely only refilled with seawater during extreme high tides, resulting in a fresher habitat with more freshwater input from rain. Furthermore, the smaller size of Third Lagoon may cause species to be more concentrated whilst Argyle Lagoon had a lower prey group count potentially because of its larger size causing prey groups to be more spread out. These environmental differences may explain the large variation of species between the lagoons, seeing as spatial distribution of invertebrates in lagoons is often related to food availability and abiotic factors (Wieking and Kröncke 2005).

Future studies may benefit from a longer time scale to increase the sample size of both prey and seabird species and therefore the accuracy of both seabird and prey composition and abundance. In addition, looking at behavioral factors, such as roosting, rearing, and feeding may be more representative of the overall health of seabird populations and provide more context for the importance and placement of MPAs for seabirds (Camphuysen et al. 2012). For sediment samples, a more accurate randomization method may increase the reliability of the data to represent the ecosystem. To standardize the amount of sediment filtered per sample, the use of a coring device rather than a shovel may also increase the accuracy of the study.

Although the benefits of MPAs for seabirds remain unclear, there is a clear correlation between seabirds and the health of the ecosystems they frequent. The information and findings discussed in this study can inform future research relating to the conservation of seabirds and the

effectiveness of designating MPAs to buffer the effects of changing environmental conditions on seabirds.

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**Data Appendix**

**Table 1.** Example of data table for raw data collection of bird species and count. Argyle Lagoon data sheet used as example with date, time, and location recorded as well as the number of each frequently spotted species counted during that time slot. Bolded columns and rows refer to the data used to create figures. Figure 2A and 2B (but with Third Lagoon data) created with the average number of each species (row labeled average). Figure 3A created with Total Spp (species) Counted column and Figure 3B created with Total Indivs (individuals) Counted column, including identical data sheets from Old Town Lagoon and Third Lagoon.

Date	Time	Location	Bald Eagle	Buffle-head	California Gull	Crow	Double Crested Cormorant	Great Blue Heron	Glaucous -Winged Gull	Canada Goose	Hooded Merganser	Juvenile Gull	Kildeer	King-fisher	Mallard	Red Breasted Merganser	Unknown Species	Total Indivs Counted	Total Spp Counted
05/03		Argyle		6			3		5		5				1	10	3	33	7
05/03		Argyle	1	5		1		1	5		15					6	3	37	8
05/16	9:50	Argyle				1			3		2	5						11	4
05/16		Argyle		1	1				4		6	3						15	5
05/20	10:10	Argyle							2	2	1	1					1	7	5
05/20		Argyle							1			1						2	2
05/21	9:38	Argyle			1			2	3		7							13	4
05/21	9:51	Argyle						1	3	1	4							9	4
05/21	2:00	Argyle						2	3		6	1		1				13	5
05/21		Argyle			1				6	3	4	2			1			17	6
05/22	8:20	Argyle						1							2			3	2
05/22		Argyle						1	2	7	3				2			15	5
05/22	1:45	Argyle							6	7		3						16	3
05/22		Argyle							6	8	3	2						19	4
05/23	9:27	Argyle					3			7	5							15	3
05/23	9:37	Argyle								7	4				4			15	3
05/24	10:11	Argyle							2	3								5	2
05/24	10:22	Argyle							1	3								4	2
05/24	2:05	Argyle				1	1		2	5								9	4
05/24	2:15	Argyle					1		4	5								10	3
		<b>Average</b>	<b>1</b>	<b>4</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>1.33333333333333</b>	<b>3.411764706</b>	<b>4.83333333333333</b>	<b>5</b>	<b>2.25</b>		<b>1</b>	<b>2</b>	<b>8</b>	<b>2</b>	<b>13.4</b>	<b>4.05</b>
		<b>Standard Deviation</b>																<b>8.875750524</b>	<b>1.66938375</b>

**Table 2.** Example of data table for data collection of prey groups and count. Argyle Lagoon data sheet used as example with date and location recorded as well as the number of each frequently spotted species counted during that time slot. Bolded columns and rows refer to the data used to create figures. Figure 4A and 4B (but with Third Lagoon data) created with the average number of each species (row labeled average). Figure 5A created with Total Spp (species) Counted column and Figure 5B created with Total Indivs (individuals) Counted column, including identical data sheets from Old Town Lagoon and Third Lagoon.

Date	Location	Worm	Crab	Snail	Bivalve	Bubble Snail	Amphipod	Anemone	Beetle	Total Indivs Counted	Total Groups Counted
5/20/2024	Argyle	8		3						11	2
5/21/2024	Argyle	11	1	1						13	3
5/22/2024	Argyle	4					1	1		6	3
5/24/2024	Argyle	1		2						3	2
5/24/2024	Argyle	16						1		17	2
	<b>Average</b>	<b>8</b>	<b>1</b>	<b>2</b>			<b>1</b>	<b>1</b>		<b>10</b>	<b>2.4</b>
	<b>Standard Deviation</b>									<b>5.567764363</b>	<b>0.5477225575</b>

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