Central
Coast
Watershed
Studies

CCoWS

Report No. WI-2022-01

26 November 2022

The Watershed Institute
Department of Applied Environmental Science

California State University, Monterey Bay
100 Campus Center, Seaside, CA, 93955

https://csumb.edu/watershed

Assessment of golf ball densities and their ecological effects on intertidal habitats of the Monterey Peninsula

Kathleen Mclaughlin (Project Manager)
Mason Donny (Fieldwork Lead)
Filipp Kashirtsev (GIS/Modeling Lead)
Jess Sutton (Writing Lead)
Joshua Beasley
Michael Biedebach
Erika Garig
Anna Herrera
Karla Jasso
Emily Kron
Alcira Lucha
Eric Pachowicz
Rebecca Roberts
Savannah Saldana
Cassandra Tice
Kathy Uccello
Janelle Vasquez-Nicholas
Caleb Yakel
John R. Olson, Ph.D. (Instructor)

Senior author contact details:
joolson@csumb.edu

Acknowledgements

We would like to thank the Monterey Bay National Marine Sanctuary for providing us the opportunity to explore this issue, consulting and offering guidance to our team, as well as taking the time to attend our final presentation. We thank Pebble Beach Company for their time in advising our team on their collection program along with permitting us access to their courses. We extend thanks to Dane Hardin and Erika Senyk of Applied Marine Sciences, Inc. for their guidance, valued feedback, and time in attending our presentation. Finally, we would like to thank Michael Weber for meeting with us and providing insight on his golf ball collection efforts.

Disclaimer: This report is the product of a pro bono study for the Monterey Bay National Marine Sanctuary by the ENVS 660 Professional Environmental Science class, Fall 2022, California State University Monterey Bay. It represents graduate student work completed within the constraints of an eight-week, limited-verification college class setting.

Table of Contents

Executive Summary

Plastic pollution in marine environments has acute and long-term effects on coastal and marine ecosystems. Golf balls are a source of marine plastic debris, especially on the Monterey Peninsula, where seven golf courses are situated along the coastline. Previous studies have focused on identifying golf ball accumulation points associated with two golf courses on the Monterey Peninsula: Pebble Beach Golf Links and Cypress Point (Pebble Beach Company and Applied Marine Science, 2022; Weber et al., 2019). However, the extent of ecological impacts of all golfing activities in this area remains unknown. To better understand the impacts of golf balls on marine environments, our study aimed to: (1) assess golf ball density along the Monterey Peninsula, (2) investigate the environmental factors affecting golf ball density, and (3) determine if there is an ecological effect of golf balls on the rocky intertidal zone. We assessed golf ball wear and density via sweeping surveys and measured intertidal species richness and diversity using quadrat sampling. We used a random forest algorithm in R for statistical modeling. In our model, we measured potential predictors associated with three categorical processes: beach, ocean, and golf course. Using these predictors, we sought to explain environmental variation within our study area that may be affecting golf ball density and species diversity at our sites.

Our collection efforts confirmed that the sites directly adjacent to Pebble Beach Golf Links accumulate more balls than the remaining sites along the Monterey Peninsula. From our models, we can infer that this is likely due to a combination of beach, ocean, and course processes in Monterey Bay, including dominant wave direction, significant wave height, distances of sites to parking lots, and distance of sites to golf course edges. Biological diversity models showed the dominant factors controlling diversity were distance to parking, average roughness of the terrain, and distance to tee box. Course processes were present in all of our models, accounting for almost half of the top nine predictors of biological diversity, indicating their importance to both golf ball densities and biological processes. More studies on the effects of golf ball degradation in marine ecosystems would help in understanding the long-term ecological impacts of golf balls. In addition, we recommend increasing collection efforts following significant storm events, as well as offering golfers biodegradable golf balls to help promote environmental awareness and reduce the amount of plastic in the ocean.

1. Introduction

It is estimated that millions of golf balls enter the ocean every year from the United States (Chawla, 2019). Monterey County alone is home to seven scenic golf courses along the Monterey Peninsula, with Pebble Beach Golf Links ranked as the number one public golf course in the country (Duncan, 2021). These courses are known for their scenic locations, making them popular among the golfing community. However, many of these courses have holes that are situated along public beaches, creating easy points of entry for stray golf balls. Due to the negative buoyancy of golf balls, once they hit the water and sink, they will continually wash in and out with the tides, eventually accumulating in sinks or becoming buried in the sandy substrate (Patton, 2021). When golf balls first enter the ocean, their ecological impacts are relatively low; however, as they break down over the years, they release microplastics and toxins into the ocean (Weber et al., 2019). Most modern golf balls are made of a polyurethane elastomer shell and a synthetic rubber core that includes zinc oxide and zinc acrylate. These substances are known to be toxic in aqueous environments, causing undue stress and damage to marine ecosystems as they break down (Weber et al., 2019).

This environmental issue was first brought to light by Alex and Michael Weber in 2016 when they discovered thousands of golf balls while free diving along the coast in Carmel, California (Paget, 2018). They eventually conducted a formal scientific study alongside Dr. Matthew Savoca of the Hopkins Marine Station, which sought to quantify marine debris shed from nearby golf courses. Combining their collection efforts with the Monterey Bay National Marine Sanctuary (MBNMS) and Pebble Beach Company (PBC), Weber et al. (2019) reported the retrieval of 50,681 golf balls from coastal environments associated with two courses in Carmel (Weber et al., 2019). Savoca reported in an interview that roughly 60,000 pounds of unrecoverable microplastics had already been shed from the balls they collected (Katz, 2019). Since then, substantial clean-up efforts have been implemented by PBC and nearby courses to address this issue.

In April 2017, PBC began weekly shoreline golf ball collections at Pebble Beach Golf Links. Following the media coverage of the Weber et al. paper in 2019, PBC began scuba collections twice per month from October through March and once per month from April through September (PBC & Applied Marine Science Inc., 2022). The goal of this work was to understand how storm surges and other tide factors influence golf ball movement and to identify golf ball accumulation points for future collection efforts. They have now completed two annual reports of their findings and collected a total of 63,888 golf balls on the shoreline in the past four years (PBC & Applied Marine Science Inc., 2022). They observed both a temporal pattern of higher golf ball densities within the winter months and a spatial pattern of specific sites having greater golf ball densities during their marine collections. They noted that the average number of golf balls appears to be declining following increased collection efforts of both shoreline and marine surveys (PBC & Applied Marine Science Inc., 2022). The amount of golf balls collected and the later stages of wear in the marine collections are predominantly dependent on wave index (mean wave height and period). There was also a correlation between higher wave indices and greater post-storm golf ball densities (PBC & Applied Marine Science Inc., 2022).

Previous studies have primarily focused their research and collection efforts on Cypress Point and Pebble Beach Golf Links, just two of the six courses situated along the Monterey Peninsula (Weber et al., 2019; PBC, 2022). The goal of this study was to expand upon the research of Weber et al. (2019) and PBC & Applied Marine Science Inc. (2022) while investigating golf ball accumulation in marine environments and its potential impacts on the rocky intertidal zone at all six golf courses along the Monterey Peninsula.

1.1 Research Objectives

At the suggestion of MBNMS, our team conducted golf ball and intertidal surveys at eight sites along the Monterey Peninsula. The main objectives of this study were to: (1) assess the current status of golf ball densities along the Monterey Peninsula including nearby golf courses not previously surveyed, (2) investigate the causes of variation in golf ball densities, and (3) determine the possible ecological effects of golf balls on the rocky intertidal zone. To map golf ball density, we conducted shoreline surveys at select sites that were within 100 m of golf courses. We modeled this density across a broad range of predictors to determine the underlying factors that influence shoreline golf ball presence. Lastly, we conducted quadrat sampling of the rocky intertidal to assess species richness and diversity as it relates to golf ball distribution. These results, in combination with previous studies, were used to recommend potential solutions to this ongoing issue.

2. Study Area and Methods

2.1 Study Sites

Our study sites span the coast of the Monterey Peninsula in Monterey County, California (Fig. 1). Sites were chosen based on their proximity to golf courses, accessibility, coastal aspect, geographic features, and presence of intertidal habitat. Selected sites had a wide range of features to ensure that a range of golf ball densities were represented (Table 1). The distance to a golf course ranged from 15 m to 87 m amongst our sites. We additionally characterized sites based on three coastal geographic features: straight coastlines, bays, and peninsulas. Of these geographic features, two or more of each type were included in our study.

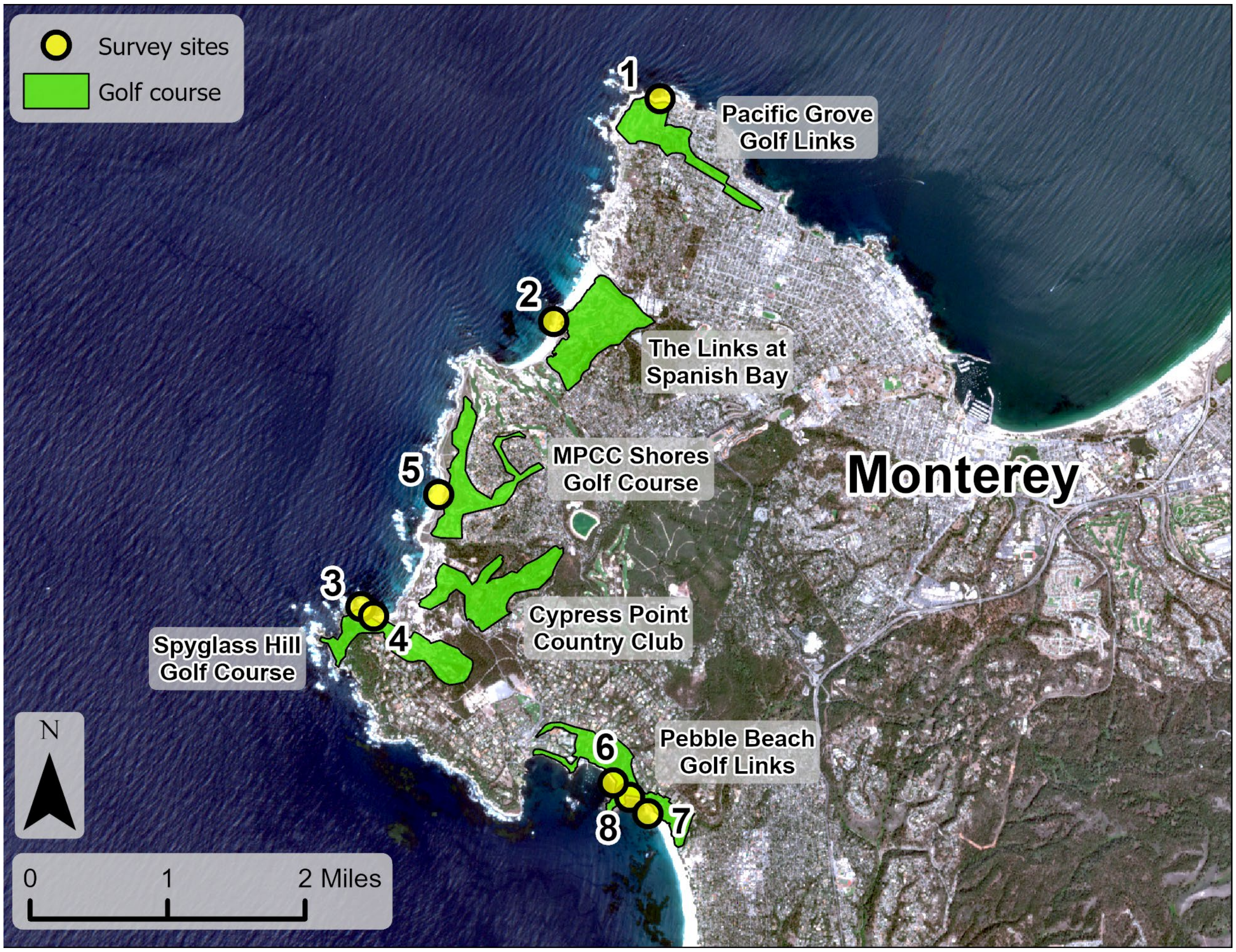


Figure 1. Study sites for golf ball and intertidal species surveys; Monterey County, California.

2.1.1 Climatological Conditions

The local climate of Monterey Peninsula is characterized by cooler temperatures and occasional fog throughout the dry season (May - October). Rainfall and storms are primarily limited to November through April, with an average rainfall of two to four inches per month (U.S. Climate Data, 2022). Wind along the coast of the peninsula runs west-northwest to north-westerly during the dry season and more westerly in winter months at an average of 3.5-4 m/sec (MBNMS, n.d). The California Current is the dominant current, which runs southward along the coast and has an undercurrent that flows northward within 100 km of the coastline (MBNMS, n.d). Throughout the year, Monterey Bay also brings in a combination of short and long-period swells of varying wave heights that have the power to move golf balls throughout the bay (Brower, 2010). The average tide height during our surveys ranged from 1.2 ft to 3.3 ft and significant wave height ranged from 5.28 ft to 18.18 ft (Table 2).

Table 1. Summary of study sites along the Monterey Peninsula in California. Slopes were averaged over three transects.

Site	Nearby Golf Course	Distance From Golf Course (m)	Coastal Aspect and Geographic Feature	Site Description
1. Point Pinos	Pacific Grove Golf Links	36	Northerly Peninsula	17% slope, sandy beach with large boulders in between
2. The Links at Spanish Bay	Links at Spanish Bay	81	Northwesterly Straight Coastline	9% slope, sandy beach with interspersed boulders
3. Cypress Point	Cypress Point Country Club	83	Northwesterly Peninsula	14% slope, sandy beach lined by rocky shoreline
4. Fanshell Beach	Spyglass Hill Golf Course	34	Northwesterly Bay	13% slope, sandy beach with rocks spread throughout
5. Granite Beach	MPCC, Shores Golf Course	87	Westerly Straight Coastline	2% slope, sandy beach with large outcroppings
6. Stillwater Cove	Pebble Beach Golf Links	15	Southerly Bay	8% slope, sandy beach and rocky substrate, bottom of a steep cliff
7. Carmel Beach	Pebble Beach Golf Links	26	Southwesterly Straight Coastline	19% slope, sandy beach surrounded by rock outcroppings
8. Carmel Beach Rocks	Pebble Beach Golf Links	20	Southwesterly Bay	17% slope, pebbly beach with large boulders on edges, used as a hazard

2.1.2 Spatial Data

We obtained spatial data as follows:

- USDA EarthExplorer Sentinel-2 (Copernicus) imagery in 10 m resolution (2022, NAD 1983 UTM Zone 10N),
- USDA Geospatial Data Gateway (GDG) NAIP county mosaic imagery in 1 m resolution for tree characterization (2020, NAD 1983 UTM Zone 10N),
- USDA GDG National Elevation Dataset (NED) Digital Elevation Map in 3 m resolution for roughness (2022, NAD 1983 UTM Zone 10N), and
- NOAA swell data (2022, Station 46239).

Table 2. Coastal conditions on the dates sampled.

Survey Date	Time	Site	Average Tide Height (ft)	Significant Wave Height (ft)	Average Wind Speed and Direction (mph)
9/8/22	13:24	1. Point Pinos	3	5.28	5.6 N
9/10/22	16:30	2. The Links at Spanish Bay	1.4	9.88	6.2 NNW
9/11/22	17:26	7. Carmel Beach	1.2	9.88	9.9 NNW
9/13/22	7:35	6. Stillwater Cove	1.3	6.25	5.6 SW
	7:35	8. Carmel Beach Rocks			
9/14/22	7:10	3. Cypress Point	1.9	18.18	3.7 NNW
9/15/22	8:45	4. Fan Shell Beach	2.5	16.67	3.7 NW
	8:22	5. Granite Beach			
9/20/22	6:51 - 9:44	1. Point Pinos	3.3	10.43	3.7 ESE
		6. Stillwater Cove			
		7. Carmel Beach			
		8. Carmel Beach Rocks			
9/21/22	7:14 - 8:58	2. The Links at Spanish Bay	3.1	15.38	3.1 N
		3. Cypress Point			
		4. Fan Shell Beach			
		5. Granite Beach			

2.2 Field Methods

We conducted all surveys during low tides, under permissible weather and wave height conditions. Wave heights for sampling days did not exceed 6 ft. We prioritized low tide mornings so that beach visitors did not collect golf balls before the sites were surveyed. We used the same transects for golf ball and intertidal species surveys. At each site, we set a 50 m backbone parallel to the shore, where there was a high probability of golf balls entering the ocean and where intertidal habitat was present. From this 50 m backbone, we ran three perpendicular 25 m transects from knee deep water (~60 cm) onto the shoreline (Fig. 2). We determined the placement of these transects along the backbone using a random number generator between 1 m and 50 m.

We collected GPS data using ArcGIS FieldMaps and a Bad Elf GNSS Receiver with 5 m accuracy. Using the streaming feature in FieldMaps, we recorded the GPS coordinates of the backbone and transects at each site.

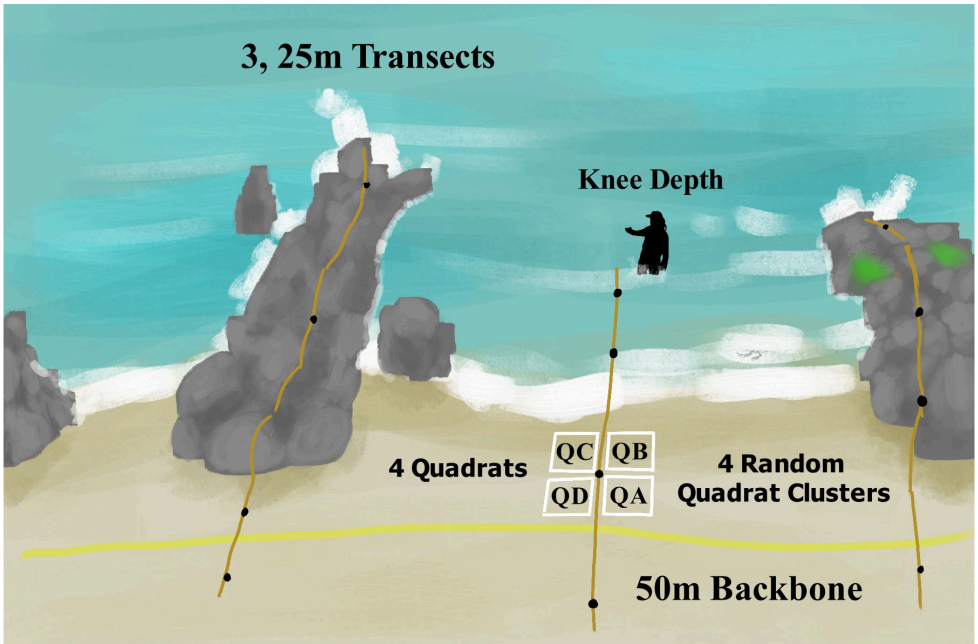


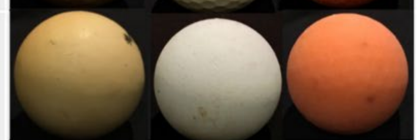
Figure 2. Transect layout for golf ball and intertidal species surveys.

2.2.1 Golf Ball Surveys

To conduct golf ball surveys, we scanned the length of the 50 m backbone and walked outward across all transects into the intertidal to knee depth height (Fig. 2). We then used these numbers to determine golf ball density at a given site.

Following a storm surge with wave heights up to 15 ft, we returned to the study sites to conduct sweeping golf ball surveys. These surveys were conducted in teams of three, with each person evenly spaced along the width of the beach and intertidal, scanning the beach for golf balls. Teams walked up to 250 m along the beach, overlapping with the previous 50 m transects. Due to high swell height, we were unable to conduct a formal sweeping golf ball survey at Site 8. We recorded all transects and golf ball locations using ArcGIS FieldMaps. After collection, we categorized golf balls into five wear categories using the classification system created by Weber et al. (2019) (Table 3).

Table 3. Categories used to identify the wear condition of golf balls. Stage 1 balls vary from pristine to good condition, whereas Stage 5 balls are notably deteriorated. Table reprinted from "Quantifying marine debris associated with coastal golf courses" by Weber et al. (2019).

Stage	Surface description	Feeling	Condition	Suitable for play	Examples
1	Intact polyurethane coating, potentially weathered surface, new to worn lettering, minor scuff marks	Waxy, Smooth	Pristine to Good	Yes	
2	No polyurethane coating, external white paint beginning to wear away, leaving paint in the dimple	Chalky, textured	Poor	No	
3	Chalky surface, dimples still visible but all paint and polyurethane gloss has worn off	Chalky, slight texture	Poor	No	
4	Smooth surface, no dimples or paint or polyurethane	Smooth, gritty	Poor	No	
5	Core is exposed in any way; ball may still have gloss as long as there is an exterior laceration	Varies	Poor	No	

2.2.2 Intertidal Species Surveys

We conducted a power analysis in R Studio to determine that 319 quadrats were needed to predict a small effect size (d = 0.2) of golf balls in the intertidal zone (power = 0.95, Type = Pearson's correlation). A small effect size increases the probability of detecting an effect of various conditions, such as presence of golf balls and weather conditions, on intertidal species health. Upon completion, we surveyed a total of 384 quadrats, surpassing our original goal.

We conducted quadrat surveys to assess intertidal species richness and diversity. Using a random number generator between 1 and 25, four groups of quadrats were placed on each of the three transects mentioned above. Each group consisted of four 1-ft^2 quadrats, labeled A, B, C, and D, for a total of 16 quadrats per transect (Fig. 2). Following Ostermiller and Hawkins (2004), species were identified to varying taxonomic levels, depending on feasibility and relevance to this study. We recorded percent cover or exact counts depending on the species encountered. See Appendix A for level of classification and method of counting. If a quadrat contained 100 or more individuals, we used random grid squares to estimate the total number of individuals in the quadrat. This involved overlaying a 5x5 square grid on the 1-ft^2 quadrat and randomly selecting three squares to count all individuals present. This cumulative number was then divided by 3 and multiplied by 25 (total number of squares) to estimate the number of individuals present in the quadrat. Additionally, we recorded slope, start time, end time, tidal height, sediment type, and date for each transect. The center of each quadrat group was recorded as a point in ArcGIS FieldMaps.

3. Modeling Methods

3.1 Random Forest

We used the random forest algorithm to model the relationship between our potential predictors and response variables. Random forest is a non-parametric, machine-learning approach that uses a large set of decision trees to inform whether hypothesized predictors are associated with an observed response (Yiu, 2019). This method worked well for our study, given that random forest predicts both continuous and categorical variables, such as golf ball density (quantitative), substrate (categorical), and presence of ocean hazards (binary). Random forest is also suitable for processing a small number of points in combination with a large list of predictors, which was ideal for our limited data collection period (Yiu, 2019).

To run this analysis, the "randomForest" package was applied in R Statistical Package, using default model parameters of *Ntree* = 2000 and *Mtry* = $\sqrt{\boldsymbol{n}}$; where *n* equals the number of predictor variables, *Ntree* defines the total number of trees to be run in the model, and *Mtry* defines the number of explanatory variables randomly sampled at each tree node (R Core Team, 2022).

We created five models to predict golf ball densities and biological factors at our sites. The first model evaluated pre-storm golf ball densities while the second evaluated post-storm golf ball densities. These models used beach, course, and ocean processes before and after a weather event on September 19th, 2022, as predictors (Table 4). The third model used the Shannon diversity index as the response. The fourth model used average percent algal cover per site as the response. The final model used average percent cover of sessile organisms per site. The biological models used beach and course processes as predictors (Table 4). All variables which were not the response in their respective model were included as predictors in other models. Our goal with the first two models was to explain golf ball density at each site, while the next three tested if golf ball density was associated with biological diversity.

3.2 Data Collection

We used a combination of field and publicly available data to compile an extensive list of variables. We modeled golf ball density, intertidal species diversity, and various species abundances across 23 variables (Table 4). When selecting predictors, we focused on three types of processes: beach, golf course, and ocean. When choosing predictors, we sought to explain environmental variation within our system that may be affecting golf ball density and species diversity among our sites. Previous studies revealed that increased storm events are strongly correlated with increased golf ball debris found on local beaches (Weber et al., 2019). For this reason, we chose to analyze ocean processes surrounding swell, wave steepness, and wind waves. Previous studies have also revealed disturbance and topography to affect marine intertidal organisms (Addessi, 1994; Hutchinson et al., 2006; Weber et al., 2019). Therefore, we also analyzed beach processes that may affect golf ball density and species diversity, such as aspect, roughness, site area (m^2), slope, substrate, and distance to nearest parking. Since all courses involved in this study are not identical, we also wanted to analyze course processes, such as direction of play, distance from course to transect, distance from tee to transect, and presence of trees and ocean hazards, to determine if certain course characteristics result in more golf balls discarded into the ocean.

Table 4. List of predictor and response variables used in our random forest models, organized by process. Response variables were also run as predictors in models when they were not the response variable.

Predictor Variables	Beach Processes	Area of site
		Aspect
		Average roughness along transect
		Average roughness at quadrat
		Distance to nearest parking
		Slope
		Substrate
	Course Processes	Direction of play
		Distance to golf course from transect
		Distance to tee from transect
		Distance from transect to nearest golf ball
		Ocean hazards present
		Tree cover
	Ocean Processes	Swell direction/height/period
		Wave steepness
		Wind wave direction/height/period
Response Variables		Average percent cover of sessile organisms
		Average percent cover of algae
		Pre storm golf ball abundance
		Post storm golf ball abundance
		Shannon-Wiener Diversity Index

4. Results

4.1 Golf Ball Results

We recorded a total of 61 golf balls, 31 prior to the swell event and 30 after the swell event (Table 5). Site 8 (Carmel Beach Rocks) had the greatest density of golf balls (0.0251) and Site 6 (Stillwater Cove) had the next highest (0.0057). However, 26 out of the 28 golf balls collected at Carmel Beach Rocks were found on site by community members just prior to our survey. Due to the proximity and timing of their collections, we chose to include these in our results and analyses. Of the 29 golf balls collected at Stillwater Cove, 17 were found where an ephemeral stream crossed onto the beach. Of the golf balls we collected, all but one were categorized as wear stage 1. Only one stage 5 golf ball was found at Site 1 (Point Pinos). The stage 5 ball was split open with only the outer shell casing present. We did not categorize the 26 balls found by community members into wear stages. Due to this discrepancy and the limited data collected, we did not conduct a formal wear analysis.

Table 5. Golf ball abundances, densities, and data collection areas (m^2) per each site.

Site	Pre-storm abundance	Post-storm abundance	Total	Density	Site area (sq. m)
1. Point Pinos	1	1	2	0.00088	2280.5
2. The Links at Spanish Bay	0	0	0	0	4048
3. Cypress Point	0	0	0	0	1304.1
4. Fanshell Beach	1	0	1	0.00037	2718.1
5. Granite Beach	0	0	0	0	6948.1
6. Stillwater Cove	0	29	29	0.00571	5082.1
7. Carmel Beach	1	0	1	0.00072	1385
8. Carmel Beach Rocks	28*	0	28	0.02505	1117.8
Total	31	30	61	-	-

*26 of these were found by community members

4.1 Intertidal Species Results

Across the 384 quadrats surveyed in the intertidal zone, we identified 34 organisms at various taxonomic levels. These included nine species of algae along with varying numbers of mussels, anemones, barnacles, sponges, snails, and crabs (Table A-1). Site 1 (Point Pinos) had the highest percent cover of algae (32.2%), while Site 5 (Granite Beach) had the highest percent cover of sessile organisms (29.5%). Alternatively, Site 3 (Cypress Point) had both the lowest percent cover of algae (4.0%) and sessile organisms (4.0%), likely because quadrats were predominantly sand or rock (Table 6). In this case, sessile organisms included giant green anemones, aggregating anemones, mussels, leaf barnacles, and acorn barnacles.

Table 6. Average percent cover at each site for algal and sessile organisms.

Site	Average Algae Cover (%)	Average Sessile Organism Cover (%)
1. Point Pinos	32.2	5.0
2. The Links at Spanish	11.0	11.5
3. Cypress Point	4.0	4.0
4. Fan Shell Beach	23.8	8.0
5. Granite Beach	11.5	29.5
6. Stillwater Cove	24.9	10.7
7. Carmel Beach	9.3	13.5
8. Carmel Beach Rocks	18.0	15.7

Following Mitra et al. (2014), we used the Shannon-Wiener Index to demonstrate health of intertidal species:

H < 1: Poor Health
H = 1-2: Moderate Health
H = 2-3: Good Health
H = 3-4: Excellent Health

Species richness was included as a metric to show the variety of species at each collection site.

In terms of sessile organism cover, seven of our sites had moderate intertidal species health (Table 7). Site 3 (Cypress Point) was the only site that showed poor intertidal species health in regards to sessile organisms. In terms of non-sessile organism counts, half of the sites showed moderate intertidal species health while the other four showed poor health.

Table 7. Shannon Index, richness, and health scores for sessile and non-sessile organisms at each site.

Site	Percent Cover (Sessile)			Counts (Non Sessile)		
	Shannon Index (H)	Richness (R)	Health Score	Shannon Index (H)	Richness (R)	Health Score
1. Point Pinos	1.221	8	Moderate	0.637	5	Poor
2. The Links at Spanish Bay	1.905	9	Moderate	1.179	5	Moderate
3. Cypress Point	0.693	2	Poor	0.080	2	Poor
4. Fanshell Beach	1.531	8	Moderate	1.117	4	Moderate
5. Granite Beach	1.212	5	Moderate	0.056	4	Poor
6. Stillwater Cove	1.416	8	Moderate	0.941	5	Poor
7. Carmel Beach	1.190	7	Moderate	1.031	3	Moderate
8. Carmel Beach Rocks	1.468	7	Moderate	1.257	6	Moderate

4.2 Modeling Results

The first of our five models predicted golf ball density per site prior to the storm event on September 19th, 2022. This model explained 95% of the variation in our data; the top three predictors were dominant wave direction at the time of the survey, distance to the nearest parking, and average wave height 10 days prior to the survey (Fig. B-1). Golf ball density was highest when waves were coming from the northwest (Fig. 3), parking was far from the site (Fig. 3), and wind waves were at their highest (Fig. B-2). Larger waves pushing towards the Monterey Peninsula may be more likely to move golf balls from the subtidal onto beaches and rocky shores, while sites with limited access to parking are less likely to have members of the public collecting golf balls. Each of these factors may lead to the positive relationships observed by the model.

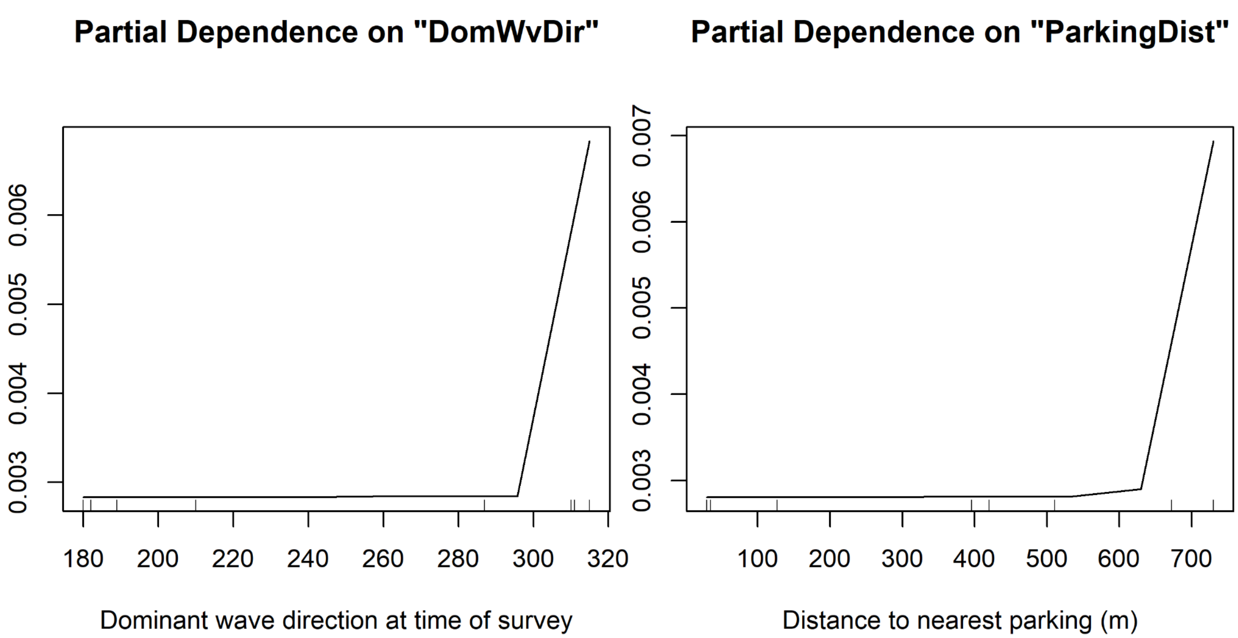


Figure 3. Partial dependence of golf ball density on dominant wave direction at the time of survey and distance from survey site to nearest public parking.

The second model predicted golf ball density per site after the weather event on September 19th, 2022. It explained 93% of the variation in our data; the top three predictors were distance from each transect to the nearest golf course edge, dominant wave direction three days prior to the survey, and wind wave direction 10 days prior to the survey (Fig. B-3). Golf ball density was highest at sites closest to golf courses (Fig. 4) and when waves were coming from the northwest (Fig. 4, Fig. B-4). Following the first model, wave direction influences the appearance of golf balls at our sites. Additionally, sites closer to courses have higher densities of golf balls (an increase from 0.0006 golf balls per m^2 to 0.002 golf balls per m^2).

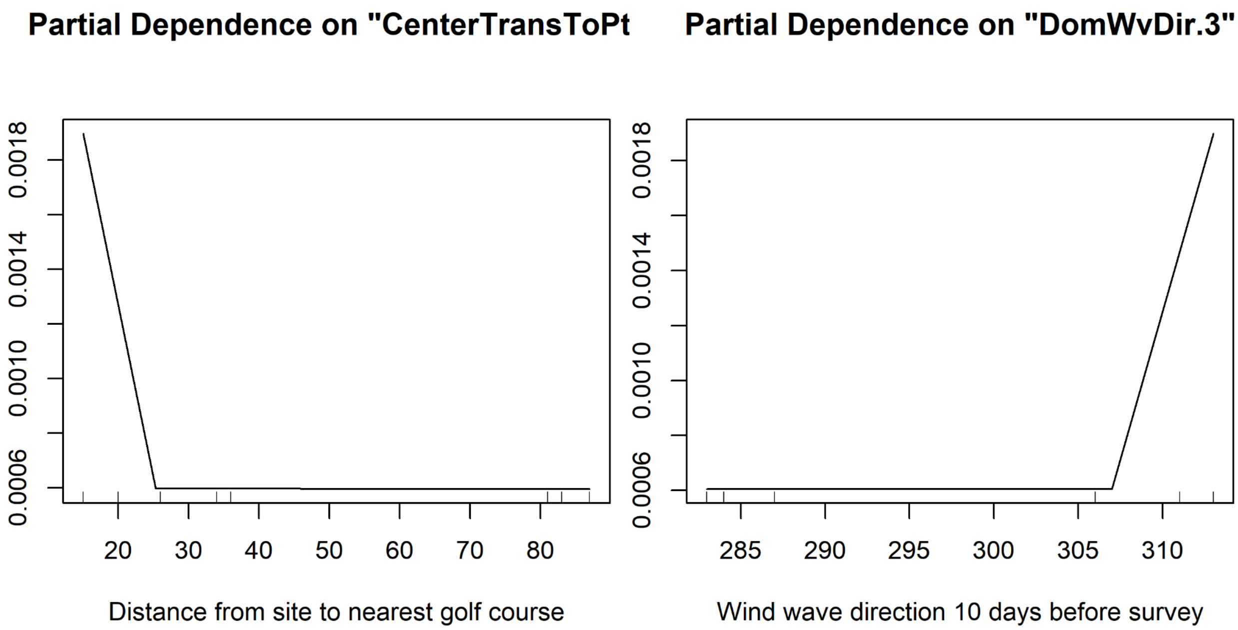


Figure 4. Partial dependence of golf ball density on distance to the nearest course edge and dominant wave direction three days prior to the survey.

The third model predicted a calculated Shannon diversity index per site. It explained 95% of the variation in our data; the top three predictors were distance to nearest parking, average roughness of our transects, and average roughness of our quadrats. Additionally, several course-related predictors are also important in this model, such as the distance from each transect to the nearest golf course edge and tee box (Fig. B-5). As distance to parking increased, the Shannon diversity increased (Fig. 5), while low roughness predicted higher Shannon diversity (Fig. B-6, Fig. B-7). The total golf ball density at each site was moderately important and showed a positive relationship between Shannon diversity and golf ball density, but this effect size is also quite small (Fig. 5). Similar to the first model, increased distance from parking may be discouraging beachgoers from visiting sites, leading to less trampling and thus higher diversity scores. The U-shaped response to roughness (Fig. B-6, Fig. B-7) is difficult to interpret, but the relationship may be influenced by our use of a 3-meter elevation map to calculate our roughness value. A higher resolution elevation map could yield more interpretable results. Additionally, intertidal organisms are highly specialized and require different conditions to thrive. The relationship between roughness and Shannon diversity may be due to different organisms present at varying degrees of site roughness.

The positive relationship between diversity and golf ball density could be explained by their co-occurrence at sites far from parking. If longer distances between sites and parking results in lower visitation by the public, this could positively affect both Shannon diversity and golf ball density.

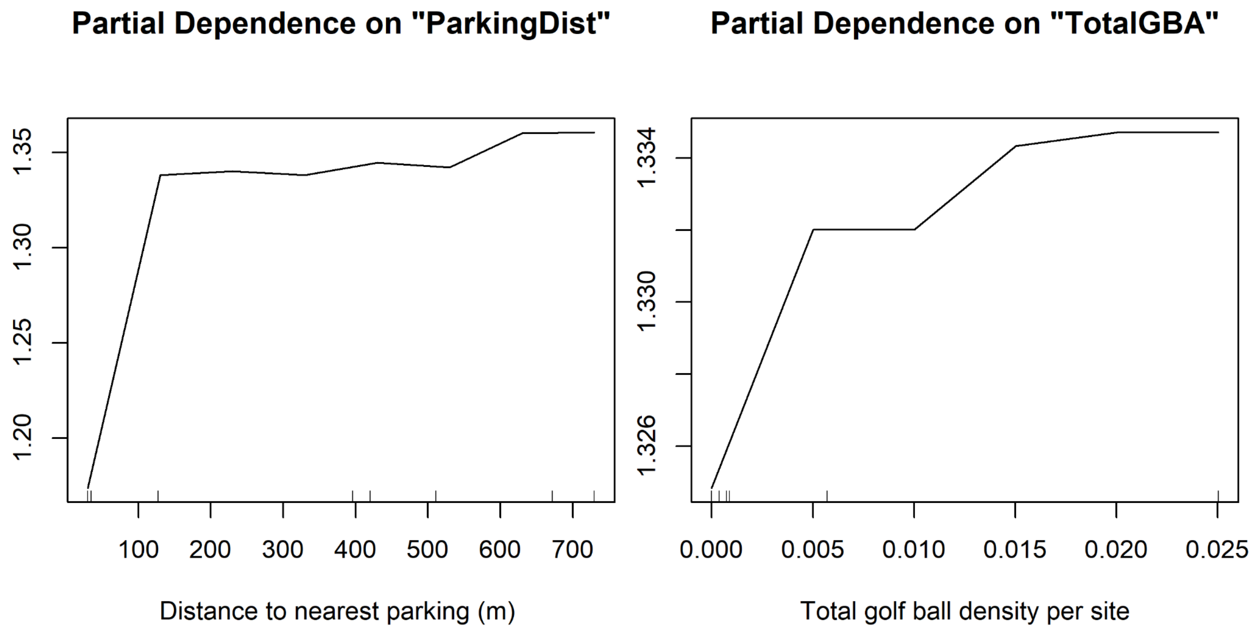


Figure 5. Partial dependence of Shannon diversity on distance to the nearest public parking and total golf ball density per site.

The fourth model predicted percent algal cover per site. It explained 33% of the variation in our data; the top three predictors were distance to the nearest golf tee, average roughness of our transects, and average roughness of our quadrats (Fig. B-8). Algal cover was highest at sites closest to tee boxes (Fig. 6) and at sites where transect and quadrat roughness were also high (Fig. B-9, Fig. B-10). The relationship between algal cover and distance to tee boxes seems counterintuitive, but most golfers are hitting balls away from the tee, potentially creating a buffer zone around the tee box where golf balls do not collect. Another explanation is tied to site roughness; algae grows on rocky, uneven surfaces where our roughness values are high, as opposed to smooth, sandy surfaces. It is possible that most of the golf tees near our site are close to rocky intertidal, rather than smoother beaches, which would make them close to algae as well.

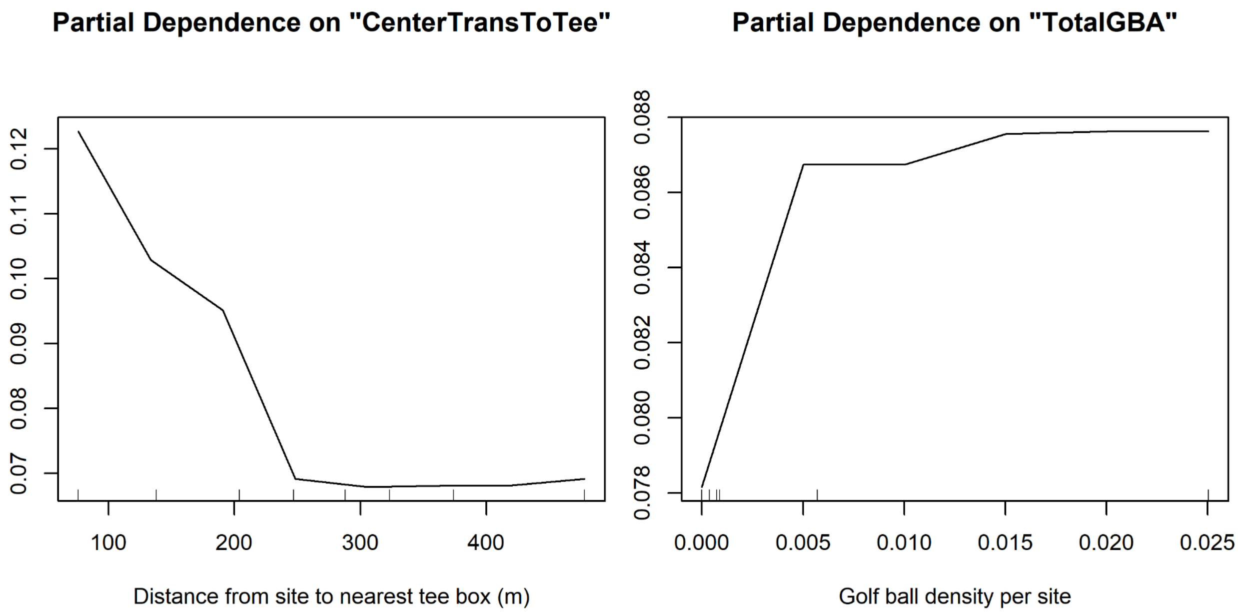


Figure 6. Partial dependence of algal cover on distance to the nearest golf course edge and total golf ball density per site.

Our fifth model tried to predict sessile organism cover per site, but due to the model's poor performance, we concluded that the results were not meaningful.

Of the top six predictors from our golf ball density models, four predictors were ocean processes, one was a beach process, and one was a course process. Of the top six predictors from our biodiversity models, five predictors were beach processes and one was a course process. Ocean processes were the most important predictors of golf ball density, while beach processes were the most important predictors of biological diversity.

5. *Discussion*

5.1 Golf Ball Density Variation along the Monterey Peninsula

Pebble Beach Golf Links has supported a volunteer-based shoreline collection program from 2017 to present. Up until 2021, they reported the collection of 63,888 balls from Stillwater Cove, Carmel Beach, and what we refer to as Carmel Beach Rocks (PBC & Applied Marine Science Inc., 2022). Across 863 surveys, they collected an average of 76 balls per outing. Across these three sites we collected a total of 58 golf balls, 29 from Stillwater Cove, 28 from Carmel Beach Rocks, and 1 from Carmel Beach. From the remaining five sites we only reported between zero and two balls collected. From these data we can confirm that the shoreline collection efforts by PBC are appropriately focused, and that the remaining sites along the Monterey Peninsula do not accumulate as many golf balls as those directly adjacent to Pebble Beach Golf Links.

Our golf ball models provide some explanation for the possible variation in golf ball densities along the Monterey Peninsula. In our pre-storm models, ocean processes were the most important factor for predicting golf ball density, with four out of the top six predictors being related to waves. A majority of the observations of dominant wave direction over a 45-day period prior to September 30th were from the north or northwest (NOAA National Buoy Data Center, 2022). Additionally, the California Current is a part of the North Pacific Gyre, which flows from Canada to Baja California, creating upwelling zones and coastal jets that are continuously pushing towards the equator. Carmel Beach and Stillwater Cove are the most southern sites on the peninsula, and therefore these ocean processes may be pushing balls southward until they are trapped at the cove. Alternatively, in our post-storm models, golf ball density was best predicted by the distance to the nearest golf course edge, followed closely by several wave predictors. Stillwater Cove and Carmel Beach Rocks are the closest sites to a golf course, at 15 m and 20 m, respectively. This lends support to the theory that golf course proximity plays a major role in golf ball accumulation. Ultimately, it is likely a combination of wave action and course processes that are influencing golf ball density at the sites we surveyed.

5.2 Potential Ecological Effects of Golf Balls on the Rocky Intertidal

Our biological response models sought to understand the effect of golf ball density on intertidal biology. The models demonstrated the importance of beach processes when trying to predict biological factors such as diversity and algal cover. However, almost half of the top 9 predictors of diversity were course processes, with the top predictor of algal cover being a course process, distance to the nearest tee box. Overall, course processes were not always negatively associated with our biological responses; for example, Shannon diversity and algal cover were both positively associated with golf ball density. One explanation for this positive correlation is the Intermediate Disturbance Hypothesis (Dial & Roughgarden, 1988). Increased disturbance as a result of higher golf ball density may be creating additional colonization opportunities for new species by physically or chemically suppressing ones that are already established. Another possible explanation for this trend is that course processes could have other effects besides the physical impacts of golf balls on intertidal habitats. Golf balls have a relatively short lifespan in the intertidal zone due to the prevailing wave direction and currents washing them out and further southward. This leaves little time for the balls to impact the rocky intertidal where we surveyed. Our data lends support to this theory in that we found almost exclusively Stage 1 worn golf balls, indicating the higher wear stages have been transported elsewhere. Golf courses could be impacting intertidal biota by other effects like chemical impacts, through either pesticides or fertilizers from golf course runoff or toxics leeched from golf balls at deeper depths adjacent to the intertidal.

Our complex model results demonstrate the need for a deeper understanding of the intertidal system in the context of golf ball emission from nearby courses. Golf balls are still a major form of plastic pollution in the area, considering tens of thousands of balls are being removed every year (PBC & Applied Marine Science Inc., 2022). In addition, we could not quantify the effect that these balls are having on biological diversity in the subtidal and diving zones beyond the intertidal because these areas were outside the scope of our study. These zones containing higher densities of further deteriorated golf balls may be a significant source of microplastics.

5.3 Golf Ball Degradation in Marine Ecosystems

Although studies have found that plastic pollution cannot be directly correlated to species population decline, it can negatively impact marine life through ingestion and habitat degradation (Browne et al., 2015). Unfortunately, plastic pollution in marine ecosystems, especially golf balls, may not be as obvious of an issue as it is in terrestrial ecosystems. A study conducted in Hawaii found that plastic debris on beaches is often chemically and mechanically degraded into microplastics which are easily concealed by sandy substrates (Corcoran et al., 2004). When golf balls enter the ocean, they often become buried in the substrate, breaking down over the years and releasing harmful microplastics and toxins into the ocean (Weber et al., 2019).

Throughout our surveys we collected one stage 5 golf ball and 38 stage 1 golf balls. Stage 1 golf balls are hypothesized to have only been in the ocean for a short amount of time; they are in excellent condition with little- to- no weathering and their polyurethane coating still intact (PBC & Applied Marine Science Inc., 2022). However, stage 5 golf balls have been worn down until their core is exposed, meaning they have been in the ocean for an extended period of time. At this stage they have likely released zinc oxide and zinc acrylate, which are known to be toxic in marine environments (Weber et al., 2019). Some balls also contain a wound rubber core that unravels to nearly 300 m of buoyant rubber string (Weber et al., 2019). Due to the buoyancy, this string may become wound around kelp and entangle wildlife. Degraded microplastics may also bioaccumulate within the system, affecting both wildlife and our community (Weber et al., 2019; Prata et al., 2021; Zhang et al., 2022).

Using our results and those of previous studies, we can infer that higher stages of golf balls (2-5) are actively being carried out to greater depths or becoming buried in the substrate where they are likely continuing to break down. We conducted our surveys during the month of September, before the larger winter swells had a chance to wash up older balls. PBC and Applied Marine

(2022) confirmed that greater density and wear stages of golf balls were found during winter months (December - February), and that higher wear was directly influenced by higher wave indices (PBC & Applied Marine Science Inc., 2022).

This is an especially important topic in Monterey, California, as all golf balls entering the ocean are coming to rest in the Monterey Bay National Marine Sanctuary (MBNMS). MBNMS is a federally protected marine area encompassing 276 miles of shoreline, housing a diverse array of sensitive habitats and species (NOAA, 2022). In order to protect this valuable resource, we need a more detailed understanding of the effects of plastic pollution on marine ecosystems, specifically those produced by golf balls. Continued research on this issue will assist in identifying golf ball accumulation hotspots and will offer helpful information on timelines for focusing clean-up efforts. Overall, this would reduce the amount of pollutants released to the environment from later degradation stages.

5.4 Limitations

We assessed the integrity of our data and data collection methods and discovered three overall limitations. First, during several surveys, community members were observed collecting golf balls independent from our collection efforts. At Site 8 (Carmel Beach Rocks), 26 out of the 28 balls collected were given to us by community members that were coincidentally collecting golf balls during our survey. Beach goers out collecting golf balls prior to our surveys could result in fewer golf balls being found and therefore, a less representative sample size. Second, due to our limited capacity and study constraints, we solely conducted shoreline surveys as opposed to in-water surveys (i.e. free diving, kayak, scuba), and therefore may have missed critical data points. Weber et al. (2019) found that diving surveys were a far more effective method of discovering golf balls than shore surveys. Lastly, our limited time frame influenced the number of surveys we were able to conduct and therefore our sample size as well. The relatively small sample size resulted in greater uncertainty in our inferences of golf ball densities. Despite these limitations, we found interesting relationships that merit a more extensive study.

5.5 Recommendations and Future Work

We evaluated a range of management actions to reduce golf ball impacts and collectively ranked them based on their feasibility (Table 8). Due to the history and architecture of Monterey's golf courses it is not feasible to recommend preventative measures such as course alterations or netting. Certain courses, such as Cypress Point Club, are strategically placed on natural rocky cliffs to allow for a scenic view of the Pacific Ocean, leaving little room for major course amendments. Therefore, our primary recommendations focus on post-emission cleanup, to minimize the amount of plastic that persists in the ocean, regardless of course policies or the number of balls hit into the ocean.

Locating cumulative hotspots and targeting them with regular clean-ups should be prioritized to mitigate the possible effects of decaying golf balls. Pebble Beach Company has put forth concerted efforts and continues to work with research divers, professional private divers, and volunteers to recover golf balls along the beach and in the ocean. We recommend expanding upon these efforts by conducting additional diving surveys following significant storm events. As mentioned above, Weber et al. (2019) and PBC and Applied Marine Science (2022) have all concurred that greater densities and higher wear statuses of golf balls are found during the winter months, when larger swells are uncovering buried balls. We also recommend the consultation of past publications and continued research on golf ball accumulation hotspots to maximize accuracy and effectiveness of clean-up efforts.

Table 8. List of the top 5 recommendations and their feasibility ranging from low to high.

Solutions	Feasibility	Brief Description	More Detailed Description
Hire Divers and Beach Walkers	High	Continue hiring golf ball clean-up staff, target specific locations	Divers would focus on post-swell/storm events to maximize cleanup and in locations where the most golf balls were found
Environmental Clean Up Fee	Medium	Used to hire additional clean-up staff, invest in research and new technology	Small fee for consumers (less than $1) which can be used to invest in research and additional clean-up staff
Biodegradable Golf Balls	Low	Minimizes plastic pollution and promotes sustainability	Provide balls at holes considered high risk of being hit into the ocean
Community Clean Up	Low	Event to bring awareness to the issue and show current efforts	Volunteers would coordinate to conduct shore surveys and there could be informational booths to increase awareness of ocean plastics
GPS Tracker in Golf Balls	Low	Track motion of golf balls lost and aid in research determining hotspots	Short-term research project - provide regular golfers with trackers for the golf balls to track movement

As previously mentioned, as golf balls break down, they release harmful microplastics into marine environments. In the last 20 years, Albus Golf and other eco-friendly brands have developed biodegradable golf balls made of 100% non-contaminant materials (Albus Golf, n.d.; Rosenburg, 2022). To ensure the recommendations we provided were feasible, one of our team members tested the performance of biodegradable balls from the company Biodegradable Golf Balls (Appendix C). On average, this team member hits a standard golf ball 160 yards using an 8-iron golf club. When testing the biodegradable balls using the same club, their shot distance was 78.8 yards, averaged over 15 swings. Despite the results, we recommend providing biodegradable golf balls as an option for new players with low club swing speed or for tourists who are more invested in seeing the Monterey Peninsula than their overall golf score. Giving players an option in their play allows for PBC to show their environmental values while promoting innovation in the biodegradable golf ball industry. We also suggest providing golfers with optional, free, biodegradable golf balls at holes directly facing the coast to reduce the number of traditional golf balls in the ocean and improve the integrity of the marine environment. This gesture would also promote environmental awareness among the community. Lastly, we suggest future research should explore the ecological effects of degraded golf balls to determine the potential impacts on marine life.

References

Addessi, L. (1994). Human Disturbance and Long-Term Changes on a Rocky Intertidal Community. *Ecological Applications*. 4(4):786-797. https://doi.org/10.2307/1942008

Albus Golf. (n.d.). Eco-friendly and Biodegradable Golf Balls. *Albus Golf.* https://www.albusgolf.com/

Brower, J. (2010). A study of storm-induced variations in the littoral sediment transport patterns of central Monterey Bay. *Division of Science and Environmental Policy, CSUMB*. https://digitalcommons.csumb.edu/cgi/viewcontent.cgi?article=1065&context=caps_thes

Browne, M. A., Underwood, A. J., Chapman, M. G., Williams, R., Thompson, R. C., & van Franeker, J. A. (2015). Linking effects of anthropogenic debris to ecological impacts. *Proc. R Soc.*, *282*. https://doi.org/10.1098/rspb.2014.2929

Colding, J., & Folke, C. (2008). The role of golf courses in biodiversity conservation and ecosystem management. *Ecosystems*, *12*, 191–206. https://doi.org/10.1007/s10021-008-9217-1

Corcoran, P., Biesinger, M. C., & Grifi, M. (2004). Plastics and beaches: A degrading relationship. *Marine Pollution Bulletin*, *58*, 80–84. https://doi.org/10.1016/j.marpolbul.2008.08.022

Dial, R., & Roughgarden, J. (1988). Theory of marine communities: The intermediate disturbance hypothesis. *Ecology,* 79(4), 1412-1424. https://doi.org/10.2307/176752

DiCarlo, D. (2018, May 4). The evolution of the golf ball. *Professional Golfers Career College.* Retrieved October 9, 2022, from https://golfcollege.edu/evolution-golf-ball/

Duncan, D. (2021). America's 100 Greatest Public Courses. *Golf Digest.* https://www.golfdigest.com/gallery/americas-100-greatest-public-courses-ranking

ESRI. 2021. ArcGIS Pro Version 2.7.3. Redlands, CA.

Hutchinson, N. Nagarkar, S. Aitchison, J.C. Williams, G.A. (2006). Microspatial variation in marine biofilm abundance on intertidal rock surfaces. *Aquatic Microbial Ecology*. 42(2):187-197. https://doi:10.3354/ame042187

Katz, B. (2019). A High Schooler Discovered Thousands of Golf Balls Polluting California's Coastal Waters. *American View, US Embassy.* https://amview.japan.usembassy.gov/en/golf-balls-polluting-california-waters/

MBNMS. (n.d.). Climate & Meteorology I. General Meteorological Conditions. *MBNMS Site Characterization, Monterey Bay National Marine Sanctuary* https://montereybay.noaa.gov/sitechar/clim1.html

Mitra, A., Pramanick, P., Chakraborty, S., Fazli, P., & Zaman, S. (2014). Mangrove Health Card: A Case Study on Indian Sundarbans. *Jordan Journal of Biological Sciences.* https://www.researchgate.net/publication/272713133_Mangrove_Health_Card_A_Case_Study_on_Indian_Sundarbans

NOAA. (2022). Monterey Bay National Marine Sanctuary (Home Page). *Monterey Bay National Marine Sanctuary.* https://montereybay.noaa.gov/welcome.html

Ostermiller, J. D., & Hawkins, C. P. (2004). Effects of Sampling Error on Bioassessments of Stream Ecosystems: Application to RIVPACS-Type Models. *Journal of the North American Benthological Society*, *23*(2), 367. https://doi.org/10.1899/0887-3593(2004)023<0363:EOSEOB>2.0.CO;2

Paget, S. (2018). Why this student collected more than 50,000 golf balls out of the ocean. *Vice News*. https://www.vice.com/en/article/bjb585/why-this-student-collected-more-than-50000-golf-balls-out-of-the-cean

Patton, D. (2021). What Is the Density of a Golf Ball? https://www.golflink.com/facts_11299_what-density-golf-ball.html

Pebble Beach Company, & Applied Marine Sciences. (2022). *Annual Report for 2021: Pebble Beach Golf Links Golf Ball Recovery Program*.

Pebble Beach Company. (n.d.). Golf Ball Recovery | Pebble Beach Resorts Green Initiatives. *Pebble Beach Resorts.* Retrieved September 20, 2022, from https://www.pebblebeach.com/green-initiatives/golf-ball-recovery/#:~:text=Pebble%20Beach%20Company%20contracts%20with%20research%20divers%20in

Prata, J.C., P. da Costa, J., Lopes, I., Andrady, A.L., Duarte, A.C., Rocha-Santos, T. (2021). A One Health perspective of the impacts of microplastics on animal, human and environmental health. *Science of The Total Environment*, 777(146094):1-13. https://doi.org/10.1016/j.scitotenv.2021.146094

R Core Team. (2022). R: A language and environment for statistical computing. *R Foundation for Statistical Computing,* Vienna, Austria. URL https://www.R-project.org/.

Rosenberg, L. (2022). *Biodegradable Golf Balls for a Low-Impact Hole-In-One. Green Matters*. https://www.greenmatters.com/p/biodegradable-golf-balls

Savoca, M. (2019). A teen scientist helped me discover tons of golf balls polluting the ocean. *The Conversation.*

Chawla, D. S. (2019*).* How Golf Is Polluting Our Oceans. *Medium; OneZero.* https://onezero.medium.com/how-golf-is-polluting-our-oceans-eddb8b59ddc9

SRI International. (2013). The California Golf Economy Summary Report. https://turfgrass.ucr.edu/reports/topics/cagolf_summary_report_jul08.pdf

Weber, A. K., Weber, M. W., & Savoca, M. S. (2019). Quantifying marine debris associated with coastal golf courses. *Marine Pollution Bulletin*, *140*, 1–8.

Weideman, E. A., Perold, V., Omardien, A., Smyth, L. K., & Ryan, P. G. (2020). Quantifying temporal trends in anthropogenic litter in a rocky intertidal habitat. *Marine Pollution Bulletin*, *160*. https://doi.org/10.1016/j.marpolbul.2020.111543

Wong, S.W.Y., Leung, P.T.Y., Djurišić, A.B. *et al.* (2010). Toxicities of nano zinc oxide to five marine organisms: influences of aggregate size and ion solubility. *Anal Bioanal Chem* 396, 609–618. https://doi.org/10.1007/s00216-009-3249-z

Yiu, T. (2019). Understanding Random Forest. *Towards Data Science*. https://towardsdatascience.com/understanding-random-forest-58381e0602d2

Zhang, E., Kim, M., Rueda, L., Rochman, C., VanWormer, E., Moore, J., Shapiro, K. (2022). Association of zoonotic protozoan parasites with microplastics in seawater and implications for human and wildlife health. *Scientific Reports*, 12(6532):1-11. https://doi.org/10.1038/s41598-022-10485-5

Appendix A - Intertidal Species Surveyed

Table A-1. Level of identification and method of counting for intertidal species surveyed.

Identification Level	Common Name	Identification Level Name	Method
Genus	Sea Lettuce	*Ulva*	Percent Cover
	Rockweed	*Fucus*	
	Tar Spot Algae	*Mastocarpus*	
	Stunted Turkish Towel	*Mastocarpus*	
	Gelidium	*Gelidium*	
	Nori	*Pyropia*	
	Iridescent Algae	*Mazzaella*	
	Abalone	*Haliotis*	Count
	Shore Crabs	*Hemigrapsus*	
	Limpets	*Tectura*	Count/Quadrat Method
	Hermit Crabs	*Paguroidea*	Quadrat Method
Order	Kelp	*Laminariales*	Percent Cover
	Encrusting Coralline	*Corallinales*	
	Upright Coralline	*Corallinales*	
	Seagrass	*Alismatales*	
Phylum	Sponges	*Porifera*	Percent Cover
Species	Pin-cushion algae	*Cladophora columbiana*	Percent Cover
	Dead Man's fingers	*Codium fragile*	
	Scouring Pad Alga	*Endocladia muricata*	
	Prionitis	*Prionitis lanceolata*	
	Sea Sacs	*Halosaccion glandiforme*	
	Green Anemone	*Anthopleura xanthogrammica*	
	Sunburst Anenome	*Anthopleura sola*	
	Aggregating anemone	*Anthopleura elegantissima*	
	California Mussel	*Mytilus californianus*	
	Leaf Barnacle	*Pollicipes polymerus*	
	Common Acorn Barnacles	*Balanus glandula*	
	Honeycomb Tube Worms	*Phragmatopoma californica*	
	Common Whelk	*Buccinum undatum*	Count
	Ochre Sea Star	*Pisaster ochraceus*	
	Pink Volcano Barnacle	*Tetraclita rubescens*	
	Periwinkle Snail	*Littorina littorea*	Quadrat Method
	Turban Snails	*Tegula funebralis*	
Subphylum	Tunicates	*Tunicata*	Percent Cover

Appendix B - Random Forest Models

Table B-1. List of codes and their translations used in random forest modeling.

Codes	Translation	Codes	Translation
Slope	Slope of transect	SWDir	Swell direction at time of survey
Substrate	Substrate of transect	WWvDir	Wind wave direction at time of survey
Aspect	Aspect (Degrees)	Steepness	Wave steepness at time of survey
Aspect.1	Aspect (Categorical)	AvgWPe	Average wave period at time of survey
NEAR_DIST	Distance from transect to nearest golf ball	DomWvDir	Dominant wave direction at time of survey
CenterTransToPt	Distance from transect to nearest golf course	SigWvHt.3	Average wave height three days prior to survey
CenterTransToTee	Distance from transect to nearest tee	SwHt.3	Swell height three days prior to survey
PlayDir	Golf play direction	SwPe.3	Swell period three days prior to survey
oceanhaz	Presence of golf course ocean hazard	WWvHt.3	Wind wave height three days prior to survey
ParkingDist	Distance to nearest public parking	WWvPe.3	Wind wave period three days prior to survey
AreaSqM	Site search area (square meters)	SWDir.3	Swell direction three days prior to survey
Shan_Div	Shannon diversity index	WWvDir.3	Wind wave direction three days prior to survey
PreGBA	Pre-storm golf ball density per site	Steepness.3	Wave steepness three days prior to survey
PostGBA	Post-storm golf ball density per site	AvgWPe.3	Average wave period three days prior to survey
TotalGBA	Total golf ball density per site	DomWvDir.3	Dominant wave direction three days prior to survey
T_avgrough	Transect average roughness per site	SigWvHt.10	Average wave height ten days prior to survey
Q_avgrough	Quadrat average roughness per site	SwHt.10	Swell height ten days prior to survey
plant_avg	Algae cover per site	SwPe.10	Swell period ten days prior to survey
cess_avg	Sessile organism cover per site	WWvHt.10	Wind wave height ten days prior to survey
Trees	Tree cover within 215 meters of site	WWvPe.10	Wind wave period ten days prior to survey
SigWvHt	Average wave height at time of survey	SWDir.10	Swell direction ten days prior to survey
SwHt	Swell height at time of survey	WWvDir.10	Wind wave direction ten days prior to survey
SwPe	Swell period at time of survey	Steepness.10	Wave steepness ten days prior to survey
WWvHt	Wind wave height at time of survey	AvgWPe.10	Average wave period ten days prior to survey
WWvPe	Wind wave period at time of survey	DomWvDir.10	Dominant wave direction ten days prior to survey

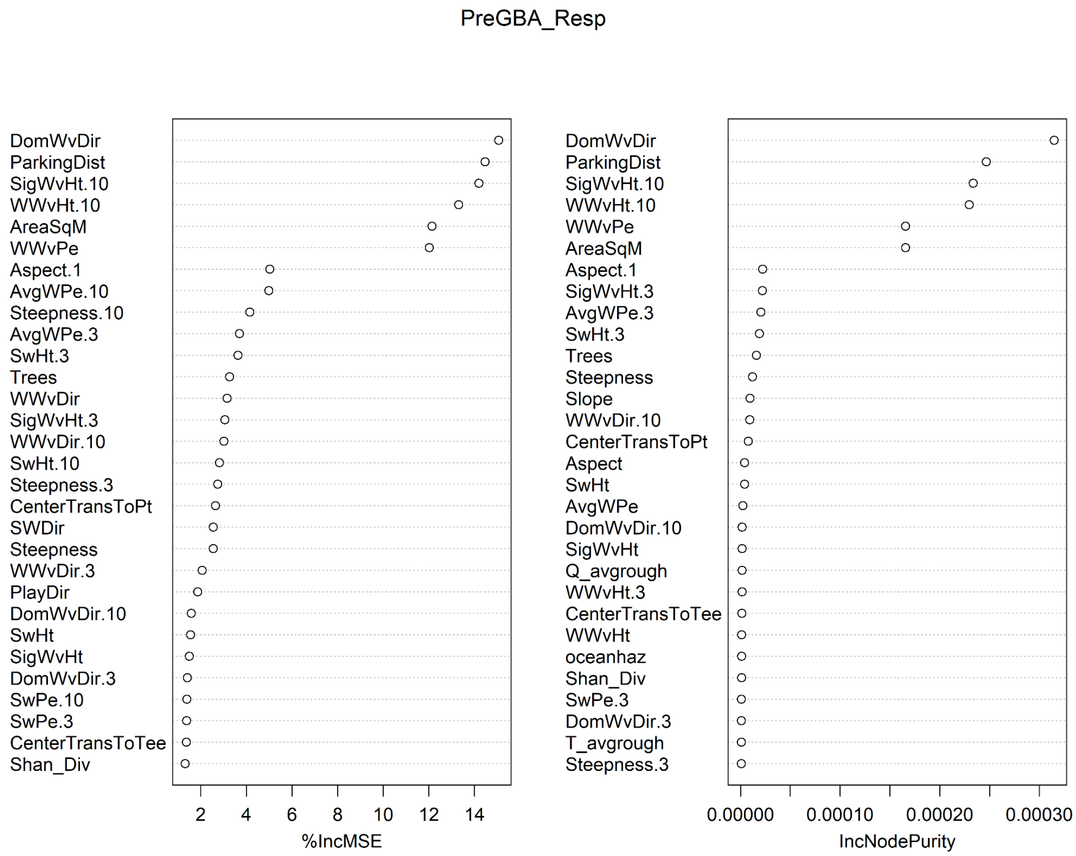


Figure B-1. Importance plot of Model 1, prior to a recent weather event, predicting golf ball density. The plot on the left describes the increase in model error when the predictor is removed, while the plot on the right describes improved model performance after each split in a decision tree, averaged over all trees in the model.

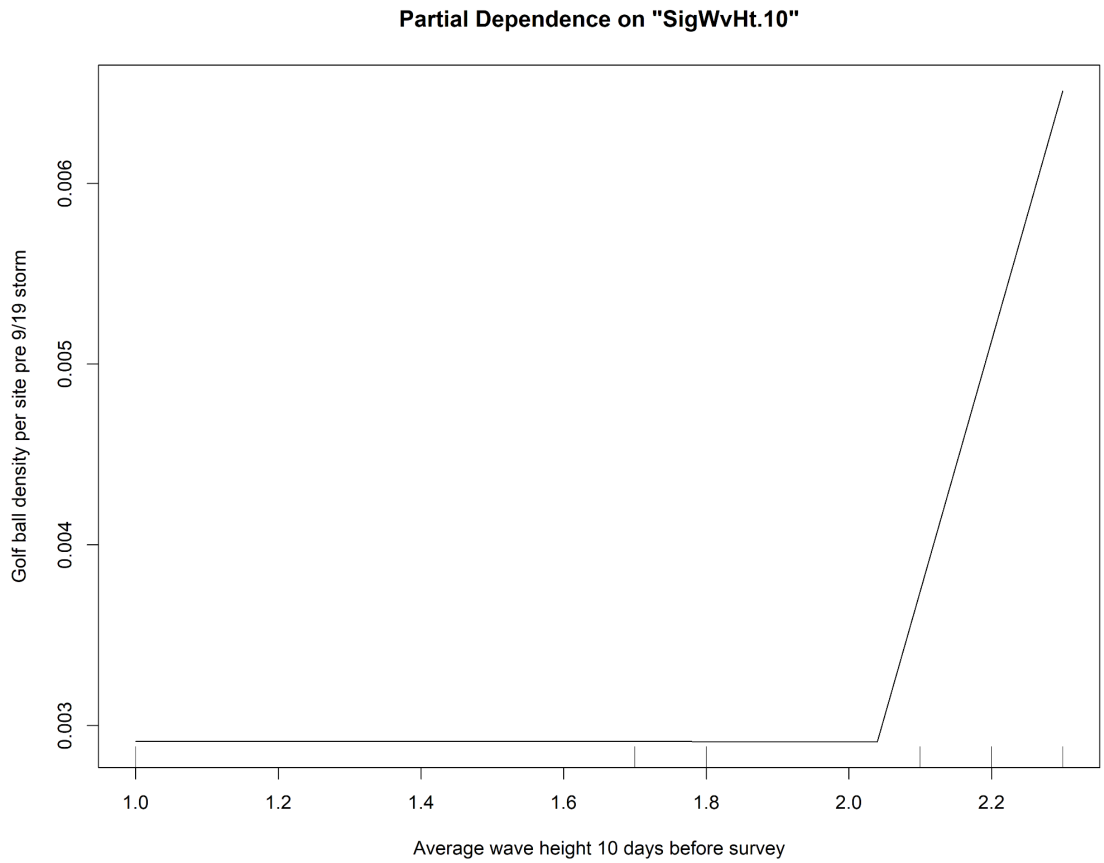


Figure B-2. Partial dependence of golf ball density on average wave height 10 days prior to survey.

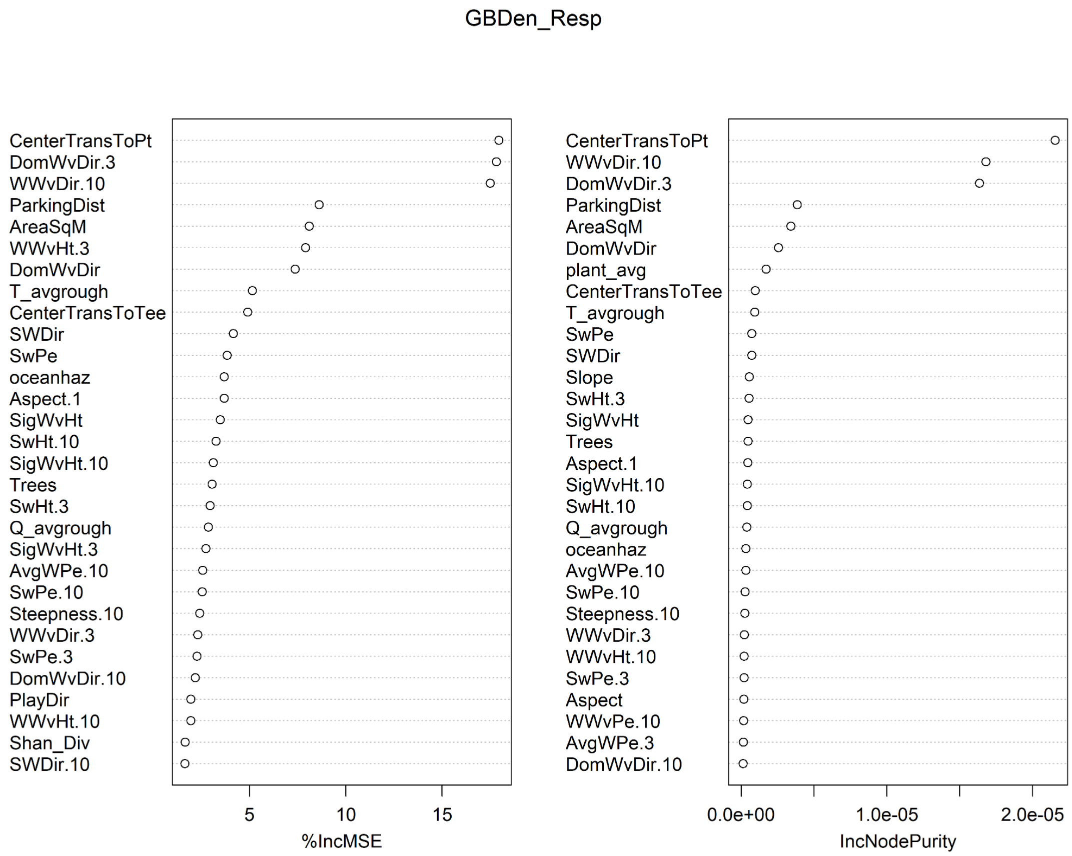


Figure B-3. Importance plot of Model 2, after a recent weather event, predicting golf ball density. The plot on the left describes the increase in model error when the predictor is removed, while the plot on the right describes improved model performance after each split in a decision tree, averaged over all trees in the model.

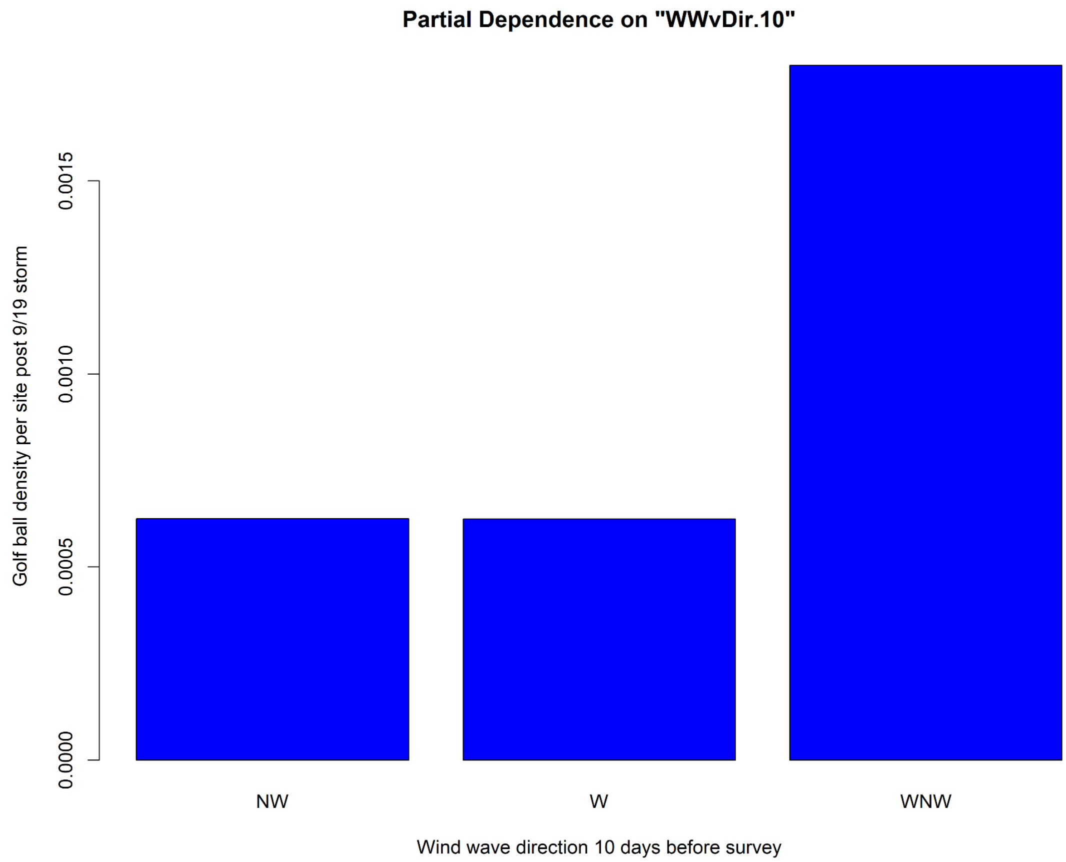


Figure B-4. Partial dependence of golf ball density on wind wave direction 10 days prior to survey.

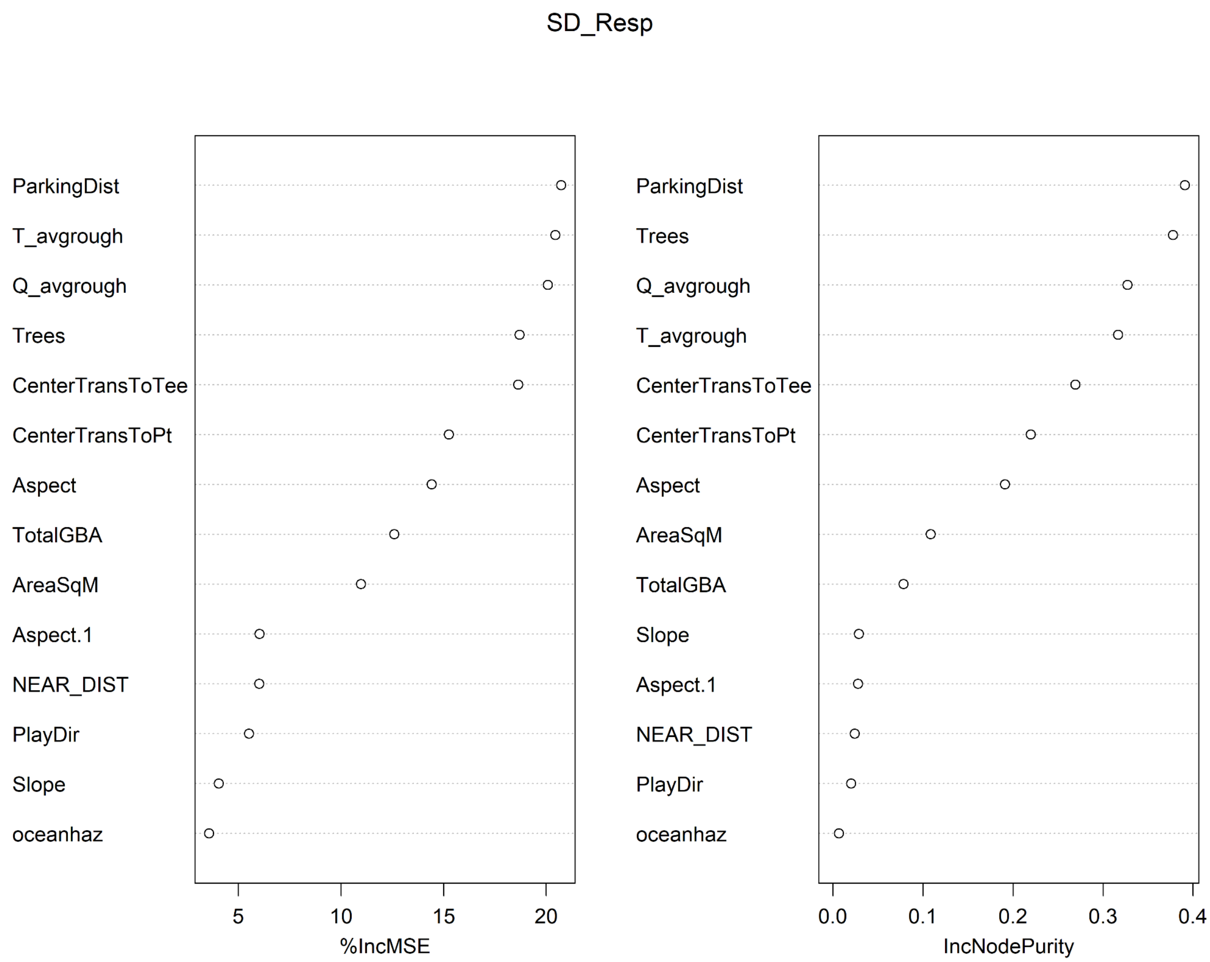


Figure B-5. Importance plot of Model 3 predicting Shannon diversity. The plot on the left describes the increase in model error when the predictor is removed, while the plot on the right describes improved model performance after each split in a decision tree, averaged over all trees in the model.

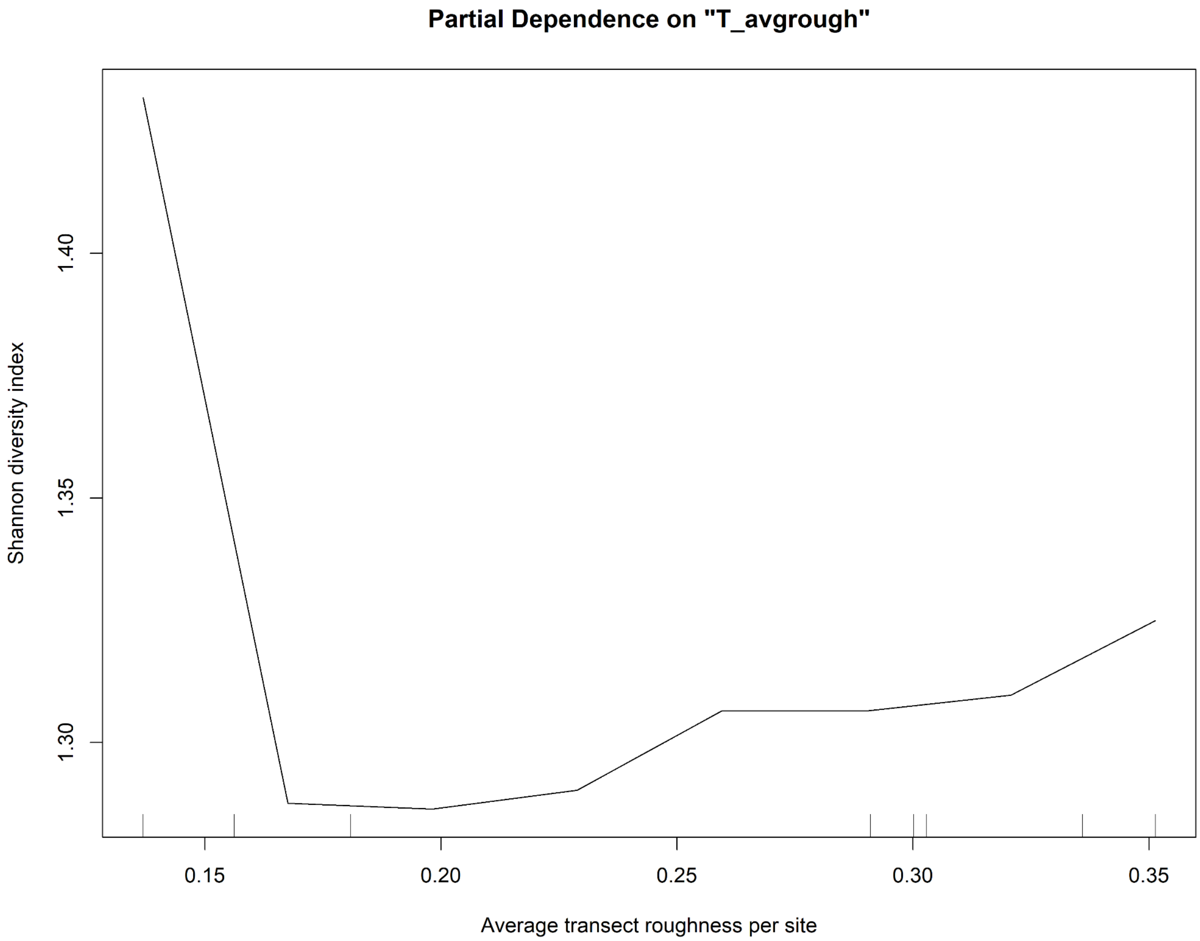


Figure B-6. Partial dependence of Shannon diversity index on average transect roughness per site.

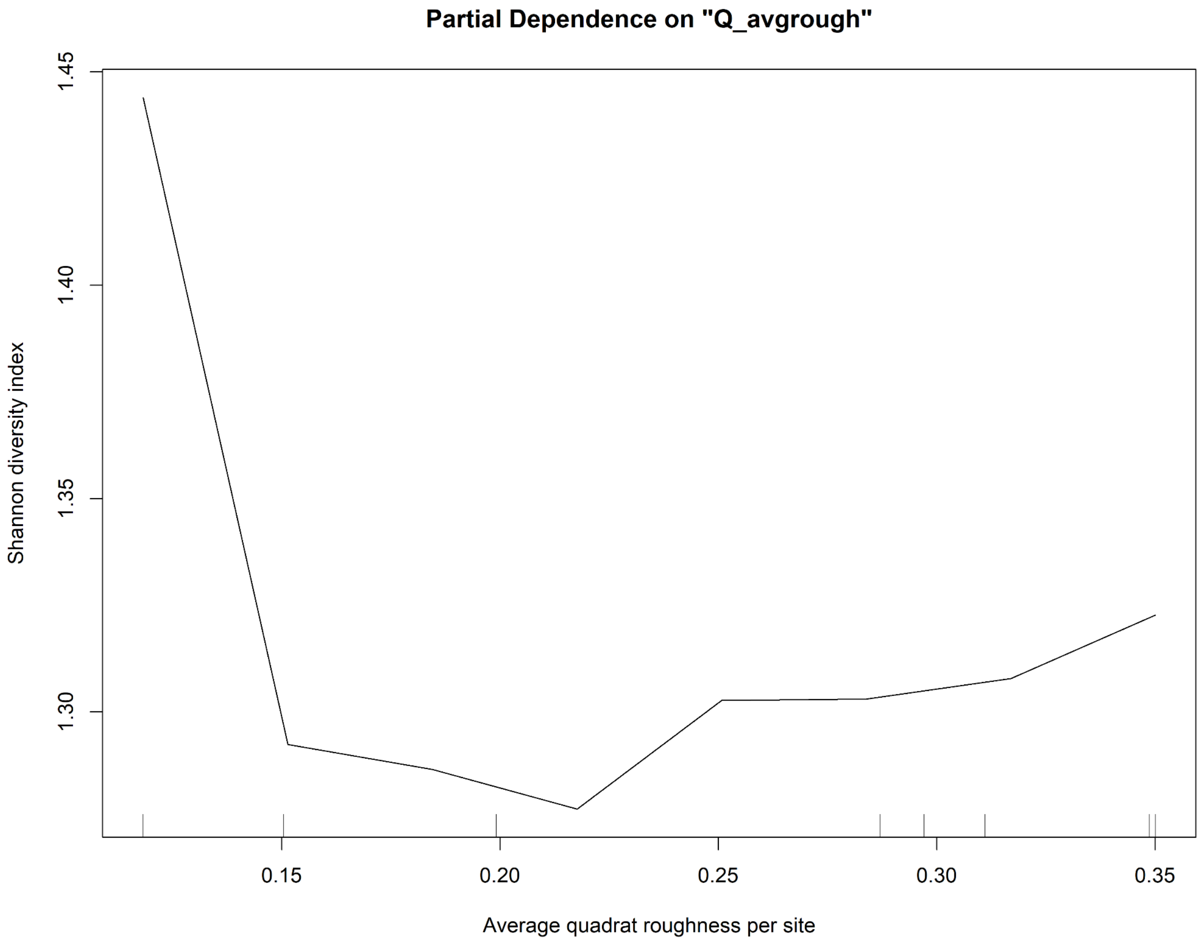


Figure B-7. Partial dependence of Shannon diversity index on average quadrat roughness per site.

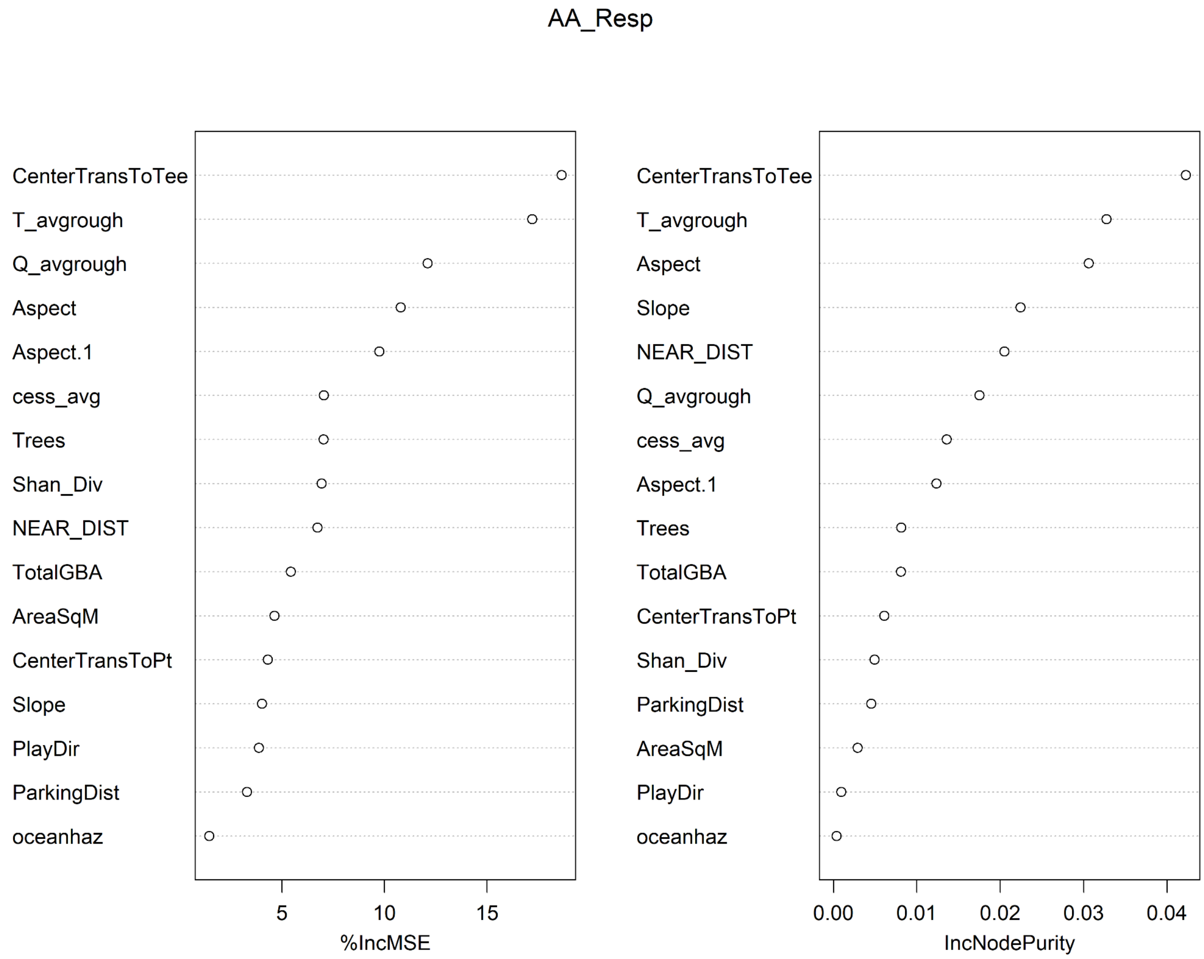


Figure B-8. Importance plot of Model 4 predicting average algal cover. The plot on the left describes the increase in model error when the predictor is removed, while the plot on the right describes improved model performance after each split in a decision tree, averaged over all trees in the model.

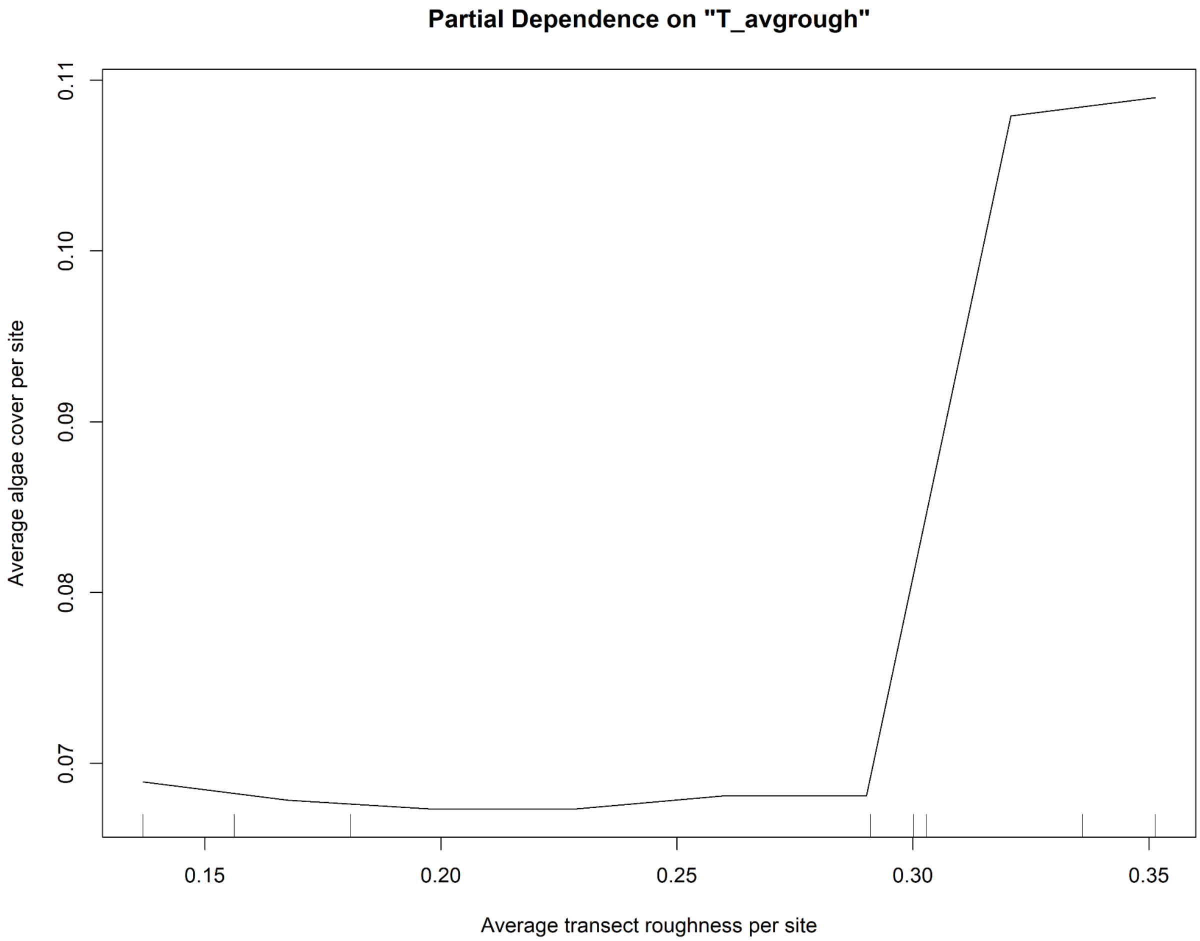


Figure B-9. Partial dependence of average algal cover per site on average roughness at transect.

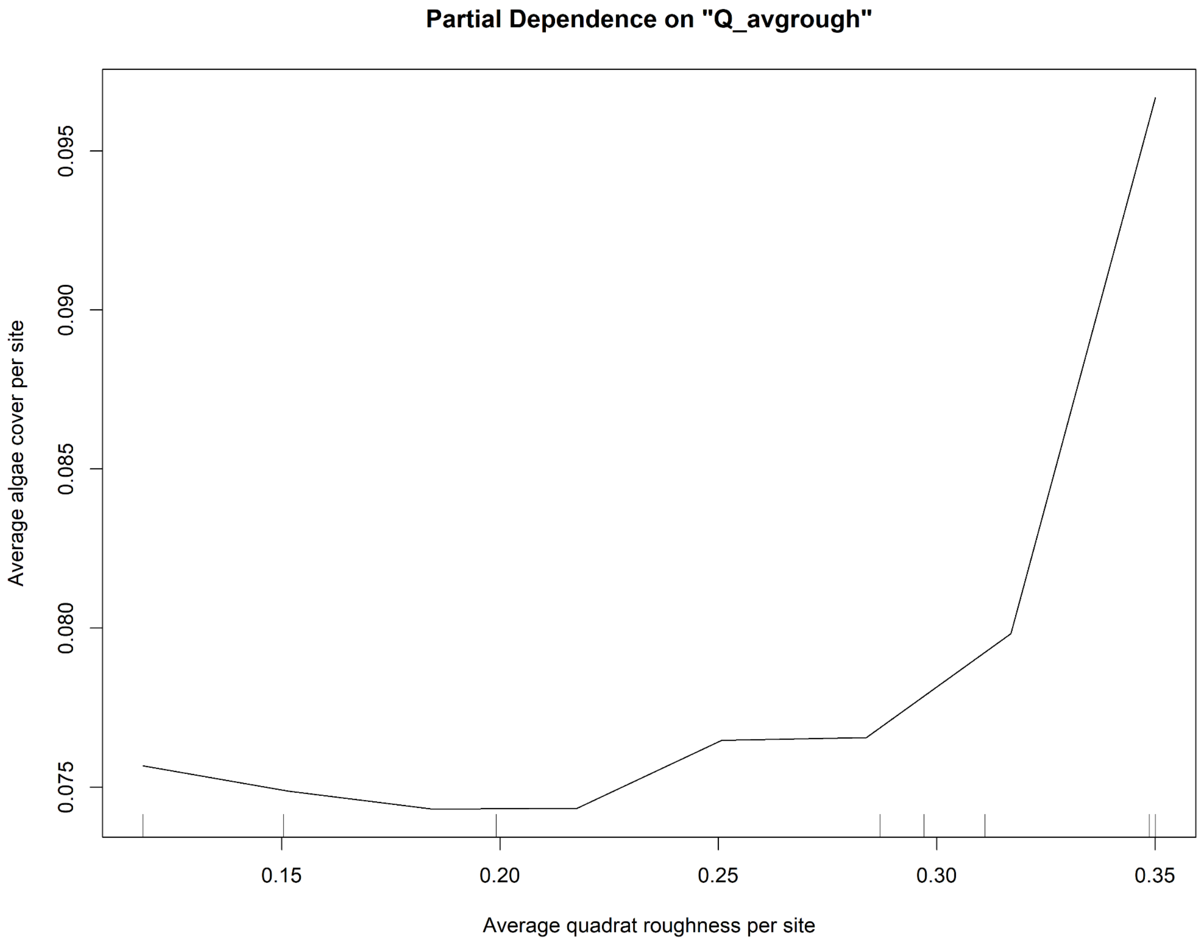


Figure B-10. Partial dependence of average algal cover per site on average quadrat roughness.

Appendix C - Biodegradable Golf Ball Assessments

Table C-1. Biodegradable ball tester golf stats.

Clubs	19 Handicap (yds)	Speed (mph)
5 Wood Stock	210	95
8 Iron Stock	160	87
Driver Stock	275	113

Table C-2. Stress test for biodegradable golf balls.

Club	Rank	Distance (yds)	Notes
8 Iron	3	78	Club groves imprinted
	4	86	
	2	65	Ball dented
	2	60	
	1	27	
	3	74	
	4	110	
	3	90	
	2	77	
	4	108	
	2	70	
	3	86	
	3	91	
	4	95	
	3	67	Split at seam
Average	2.9	78.9	-

Rank	Explanation
1	Poorly hit ball - wither off toe/heel of club, would be described as a mis-hit
2	Hit okay - on face of club but not quite right
3	Hit well - within millimeters of center of club
4	"Pured it" - center of club, perfect shot

Table C-3. Statistics of biodegradable golf balls at 3 various holes on Salinas Fairways Golf Course.

Hole	Club	Rank	Distance (yds)	Notes
10	Driver	2	133	Low ball - ran right
	5 Wood	1	82	Topped ball - rolled a bit and ball broke
	9 Iron	3	65	Hit well - didn't get much lift, felt non-responsive
	56 Degree	3	33	Especially unresponsive on high loft club
11	Driver	3	138	Hit well - straight
	5 Iron	1	62	Hit wierd off of strange dirt and dead grass.
	5 Wood	3	90	Ball split
	6 Iron	3	45	Low runner
13	Driver	3	121	Hit into wind - ball was very dented
	6 Iron	3	86	Ball split
	8 Iron	3	74	Low launch angle

Appendix D - Data Package Contents

- Intertidal Field Guide - pdf file
- Raw biological survey data - Excel table
- Random Forest input tables - csv tables
- GIS data
    - Golf courses - polygon shapefile
    - Golf ball collections - point shapefile
    - Quadrat locations - point shapefile
    - Transect locations - line shapefile
    - Roughness layer - raster file
    - Tree cover layer - csv table