GEOSPATIAL ANALYSIS AND COMPARISON OF HABITAT COSTS FOR RESIDENT SARASOTA BAY BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*)

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Abstract

The Sarasota Dolphin Research Program (SDRP) studies a resident Florida bottlenose dolphin population that faces many threats from human activities. These dolphins concentrate in different areas seasonally, possibly in response to changes in the distribution of prey or predators. Movement from one location to another involves certain "costs" to the dolphins, which are defined in this project as the potential for negative environmental interactions (natural and anthropogenic). Using an updated habitat map for the SDRP study area and a geoprocessing model, a cost analysis was performed in order to compare the cost values of eight primary habitat types. Results indicated that Mangrove and Channel are the most costly, while Open Bay and Pass are the least costly. I hypothesized that dolphins will use habitats with lower costs more frequently than habitats with higher costs, but previous research and SDRP photographic survey data show that these dolphins frequently use dredged channels to move between areas, and at the population level they do not use any habitat type disproportionately to its availability.

Introduction

Started in 1970, the Sarasota Dolphin Research Program (SDRP) is the longest-running study of a wild dolphin population in the world. Through the use of long-term systematic surveys, the program focuses on the study of a resident bottlenose dolphin (*Tursiops truncatus*) population that occupies a coastal area that stretches from Tampa Bay to Venice, Florida (Wells, 2014). This work continues year-round, and the SDRP is now a center for research into the biology of wild bottlenose dolphins. In addition to its dedication to improving our understanding of how these animals live, how they interact with their environment, and how they are affected by human activities, the program also translates scientific research into conservation action and shares what it has learned, with the support of the Chicago Zoological Society (CZS), via public education and outreach (*Nicks 'n' Notches*, 2014).

Most of the Sarasota dolphins are permanent residents, and studies have revealed that there are currently about 160 dolphins in this community (Wells, 2014). These dolphins are an identifiable social unit with roughly defined geographical boundaries, and they display well-studied natural behaviors and distribution patterns, including habitat selection, foraging ecology, social interactions and reproduction strategies (SDRP, 2014). This resident population is not currently listed as threatened or endangered. However, as these dolphins live within an environment that neighbors a heavily urbanized region, they face many threats from human activities. For example, they share the waterways with hundreds of vessels. As the tourism industry in Florida continues to grow, recreational marine activity becomes ever more popular. As a result, the potential for human-dolphin interactions is increasing, putting these bottlenose dolphins at greater risk of injury or suffering disruption to their natural behaviors.

Dolphins from this population concentrate in different areas seasonally, possibly in response to changes in the distribution of important prey species (Irvine et al., 1981) or the abundance of predators (Wells et al., 1980). For example, dolphins may shift their distribution in response to seasonal migrations of striped mullet (*Mugil cephalus*), which migrate during the fall from the bays into the Gulf to spawn and back into the bays during the spring (Scott et al., 1990). Dolphins are also frequently associated with seagrass patches, which are important habitats for soniferous fish that dolphins commonly prey on (Barros and Wells, 1998). Learning which habitats dolphins are most likely to use is an important part of understanding more about their behavior and life histories, as well as implementing effective management strategies that promote conservation. Movement from one habitat area to another involves certain “costs” to the dolphins in question. These costs can be defined broadly as risks to dolphin well-being (e.g. exposure to possible boat strike, predation, sting ray injury, conspecific aggression, entanglement in or ingestion of fishing gear, disturbance, pollution exposure, etc.) or energy expenditure from moving from one area to another. The primary focus of this project was to conduct a habitat cost analysis of the SDRP study area using geospatial technologies to determine if certain available habitat types are more costly or beneficial than others to dolphin movements.

The specific objectives of the project were as follows: (1) update and expand the bottlenose dolphin habitat map for the SDRP study area using geographic information systems (GIS) technology, (2) create a cost surface raster for the SDRP study area using a geoprocessing model that displays the cost for dolphins moving through each cell of the habitat map, (3) compare the generated cost values of each primary habitat type with survey data and research on resident dolphin habitat use to determine if dolphins are more likely to avoid habitats with higher cost values, and (4) examine the public policy conservation regime and policy alternatives potentially available to mitigate anthropogenic interactions in this region. Based on the environmental inputs chosen to generate the cost surface, I hypothesize that the Channel and Mangrove habitats will have the highest mean cost values, the Gulf and Open Bay habitats will have the lowest mean cost values, and that resident dolphins will use habitats with lower mean costs more frequently than habitats with higher mean costs.

Methods

Habitat Map

The purpose of the habitat map was to identify habitat types available to resident Sarasota Bay bottlenose dolphins. The extent of the map covers portions of coastal Sarasota, Manatee, and Hillsborough counties, Florida. This map is an updated and expanded version of an existing 2006 habitat map produced by Janet G. Gannon. Using ArcGIS 10.1, a fishnet with 200 meter cell width and 200 meter cell height was created for the SDRP study area and overlaid on the 1-foot resolution aerial imagery for Sarasota (collected February - March 2012), Manatee (collected March 2012), and Hillsborough (collected December 2012 - January 2013) counties. The habitat map and all layers created for this project were projected to the NAD 1983 UTM Zone 17N coordinate system. The northern extent of the study area represented in this map is the Big Bend Power Station, Apollo Beach, the southern extent is Sharky's on the Pier (just south of Venice Inlet), and the western extent is two miles from the shoreline into the Gulf of Mexico. Cells (polygons) that intersected areas available to dolphins were given a habitat classification and a mean depth or elevation value.

Bathymetry and topography data were downloaded using the National Geophysical Data Center (NGDC) Bathymetry Viewer from the Florida and Eastern Gulf of Mexico digital elevation model (2001). Some of the polygons within the fishnet have positive elevation values instead of negative depth values because they intersect land or are exposed during low tide. After the data were downloaded as a raster file and projected to the proper coordinate system, the mean depth or elevation value in meters was calculated for each polygon using the Zonal Statistics as Table tool. The resulting table was then joined to the fishnet in order to create a bathymetry attribute for the habitat map.

One of eight primary habitat classifications was given to each polygon: Channel, Gulf, Mangrove, Open Bay, Pass, River, Sandflat or Seagrass. The depth and distance criteria used to define several habitats for the 2006 map were also used for the 2013 map. Channel is defined as dredged boating channels, including the Intracoastal Waterway (ICW). Gulf is defined as nearshore Gulf of Mexico waters. Mangrove is defined as areas within 100 meters of mangrove roots. Open Bay is defined as estuarine waters greater than or equal to 2.5 meters in depth and at least 200 meters from the shoreline. Pass is defined as inlets connecting the estuarine and Gulf of Mexico waters, which are characterized by deep water (up to 10 meters) and strong currents. River is defined as riverine waters geographically within the Manatee River, Little Manatee River, Braden River, Bowlees Creek, Whitaker Bayou, Hudson Bayou, and Phillippi Creek systems. Sandflat is defined as unvegetated bottom (mud or sand substrate) less than 2.5 meters in depth. Seagrass is defined as continuous and/or patchy seagrass beds less than 2.5 meters in depth. The area in square kilometers and the percentage of the study area that each primary habitat type represents were calculated and incorporated into to a table.

The Channel, Gulf, River and Seagrass habitats were given secondary classifications to allow for greater detail to be examined within these four habitat types. Canal is a sub-habitat of Channel and is defined as dredged boating channels that penetrate the shoreline. Deep Gulf is a sub-habitat of Gulf and is defined as nearshore Gulf of Mexico waters greater than or equal to six meters in depth. Shallow Gulf is a sub-habitat of Gulf and is defined as nearshore Gulf of Mexico waters less than six meters in depth. In addition, Shallow Gulf was given a secondary classification to allow for greater detail to be examined within this sub-habitat type. Sandbar is a sub-habitat of Shallow Gulf and is defined as extremely shallow sandflats within the Gulf of Mexico that become completely or partially exposed during low tides. It should be noted that sandbars are very dynamic within this study area and are constantly subject to change. River Channel is a sub-habitat of River and is defined as navigable boating channels within a riverine system. River Vegetated is a sub-habitat of River and is defined as areas with seagrass, mangrove, and/or marsh present within a riverine system. River Unvegetated is a sub-habitat of River and is defined as areas with no visible seagrass, mangrove, and/or marsh present within a riverine system. River Unknown is a sub-habitat of River and is defined as areas where it could not be visually determined if vegetation was present or not within a riverine system. Continuous is a sub-habitat of Seagrass and is defined as areas with large, dense patches of seagrass. Patchy is a sub-habitat of Seagrass and is defined as areas with small, dispersed patches of seagrass.

The classification of individual polygons was done using a 50 percent or more rule with the habitat types described above. If a polygon was 50 percent or more water, then the polygon was given a habitat classification. If a polygon did not meet this requirement, then it was left unclassified in order to display land. This was consistent with what Gannon did in 2006. The exception to this rule was the Canal sub-habitat, as canals in the study area tended to be small and rarely filled at least 50 percent of the polygon. When classifying a polygon, it was assigned the habitat or sub-habitat type that occupied the majority of the water area within that polygon. For the Gulf polygons along the beach, the high tide line was used to determine if a polygon met the 50 percent or more rule. Aerial imagery for the three aforementioned counties, reference layers downloaded from the Florida Fish and Wildlife Conservation Commission (FWC) website, the ESRI World Imagery Basemap and Google Earth were all used to aid in classification. However, a total of 241 polygons within Sarasota Bay could not be identified using imagery or reference layers alone. Of these polygons, 117 were selected to ground-truth (on-site field sampling and verification) via snorkeling, and the remaining unknown polygons were interpolated based on the results of the ground-truthing.

Dolphin Sightings

In order to compare dolphin movements within the study area with the updated habitat map, 2013 photographic survey data for 10 dolphins of different age classes (five female and five male) were acquired from the SDRP. These data included the identification code for each dolphin, the date each dolphin was observed and photographed during 2013, and the geographic coordinates (decimal degrees) of the survey boat at the time of each sighting. These data were imported into ArcGIS 10.2 as individual point shapefiles for each dolphin and then projected to the proper coordinate system. A habitat attribute was added to each shapefile and populated with the primary habitat type the dolphin was found in during each sighting. The total number of times all 10 dolphins, all females and all males appeared in each primary habitat type were counted and incorporated into a table.

Cost Surface

Using ArcGIS 10.2, a geoprocessing model was created in order to generate a dolphin movement cost surface for the study area using four environmental inputs. The second major function of this model was to extract a portion of the cost surface corresponding to a user-selected primary habitat type and output several cost statistics for that habitat to a table. The importance of this tool is that it is able to demonstrate the degree to which each habitat type can negatively impact dolphin movement. High costs represent a greater potential for negative environmental interactions (natural and anthropogenic) within a habitat and thus more difficult movement for dolphins, while low costs represent a lesser potential for negative interactions and thus easier movement. Sub-habitats were omitted from the cost analysis because sub-habitats corresponding to the same primary habitat type have very similar characteristics.

Important aspects of dolphin ecology that also influence cost, such as prey availability and predator abundance, were not included in this analysis because data were not available. SDRP does have an ongoing prey sampling project to determine how prey species are distributed among habitats and how the distribution of prey changes seasonally (McCabe et al., 2005), but little is known about shark abundance and distribution in this region (McHugh et al., 2011). However, these excluded inputs could be incorporated into the geoprocessing model if they were available, and doing so would improve the cost analysis. Other data sources such as water temperature and salinity were not used because movement does not appear to be influenced by these environmental parameters in any recognizable way (Irvine et al., 1981).

The four inputs used to generate the cost surface were bathymetry, distance to major channels, distance to the shoreline and distance to a Gulf of Mexico boundary two miles offshore. The bathymetry raster is the mean depth or elevation of each habitat cell in meters. The major channels feature class, which was downloaded from the FWC website, displays all major dredged boating channels in the study area as polylines, including shipping lanes and the Intracoastal Waterway (ICW). The shoreline feature class shows all shorelines (natural and hardened) as defined by the edges of the habitat map. The Gulf of Mexico boundary feature class is a polyline two miles offshore, which represents the approximate western extent of the SDRP study area, depending on the specific project. For the purpose of this project, these four inputs are considered as the primary environmental parameters negatively affecting dolphin movement and other associated activities. Shallow depth and proximity to channels, the shoreline or the Gulf boundary are considered costly to dolphins in this scenario. When moving through very shallow water, dolphins are at greater risk of becoming beached, being injured by stingrays or being struck by flats boats. Swimming in or near dredged channels, which are essentially highways for marine traffic, puts dolphins at greater risk of being struck by fast-moving boats. Canals, docks and recreational fishermen are common along the shoreline, so swimming closer to the shore exposes dolphins to injury from vessels and puts them at risk of becoming entangled in or ingesting fishing gear. As dolphins move closer to the Gulf boundary, they increase their distance from the shelter and resources provided by enclosed bays.

The first step of the geoprocessing model was to calculate the Euclidean distance for the distance to major channels, distance to the shoreline and distance to the Gulf boundary feature classes. The resulting three distance rasters and the bathymetry raster were then all reclassified into files with four different cost values, each representing a range of values (distance or depth) from the previous layer. These four reclassifications were then summed using the Raster Calculator tool into the study area cost surface, with each layer given an equal weighting of 25 percent. The next step was to extract a portion of the cost surface corresponding to a user-selected primary habitat type using the Con tool in order to visualize the cost of each habitat. The final step of this model was to generate a dBASE table with the minimum, maximum and mean cost values for that habitat using the Zonal Statistics as Table tool.

The model was run a second time using different weightings for the four inputs. This generated a second cost surface and new cost values. Research has shown that resident dolphins frequently use channels as a means of travelling and are more abundant in passes and along the Gulf shore in winter (Irvine et al., 1981). Therefore, the weightings were changed in order to demonstrate that not all environmental inputs have the same impact on dolphin movement, as using equal weightings in the model would suggest. The weightings of distance to major channels and distance to the Gulf of Mexico boundary were decreased to 20 percent each, while the weightings of bathymetry and distance to the shoreline were increased to 30 percent each.

Results

Habitat Map

There are eight primary bottlenose dolphin habitats recognized by SDRP, and each one represents a different percentage of the study area. Though the study area does not fully encompass Tampa Bay and only extends two miles into the Gulf of Mexico (Figure 1), the Open Bay and Gulf habitats combine to represent over 60 percent of this region (Table 1). Open Bay has the greatest total area of any habitat (Table 1), which is due to it being represented in three major zones: Tampa Bay, Sarasota Bay and Palma Sola Bay. Though a section of the ICW does cut through the middle of Sarasota Bay, it was depicted as Open Bay instead of Channel since it met the classification requirements for the former habitat. Pass has the smallest total area of any habitat (Table 1), which was expected since this habitat only covers the inlets connecting the Gulf of Mexico and estuarine waters behind the barrier islands. Though River does include numerous small creeks along the coastline, the two freshwater systems that make up the majority of this habitat are the Manatee and Little Manatee Rivers (Figure 1). Seagrass is distributed throughout the study area, but many seagrass beds are located close to the shoreline where the water is very shallow (Figure 1). As the water gets deeper and light penetration becomes limited, Sandflat tends to persist over Seagrass (Figure 1).

Table 1. Area and the percentage of the study area that each primary habitat type found within the SDRP study area represents.

Habitat Type	Area (km^2)	% of Study Area
Channel	53.56	7.14
Gulf	217.84	29.03
Mangrove	32.28	4.30
Open Bay	239.92	31.98
Pass	14.28	1.90
River	40.16	5.35
Sandflat	60.04	8.00
Seagrass	92.24	12.29

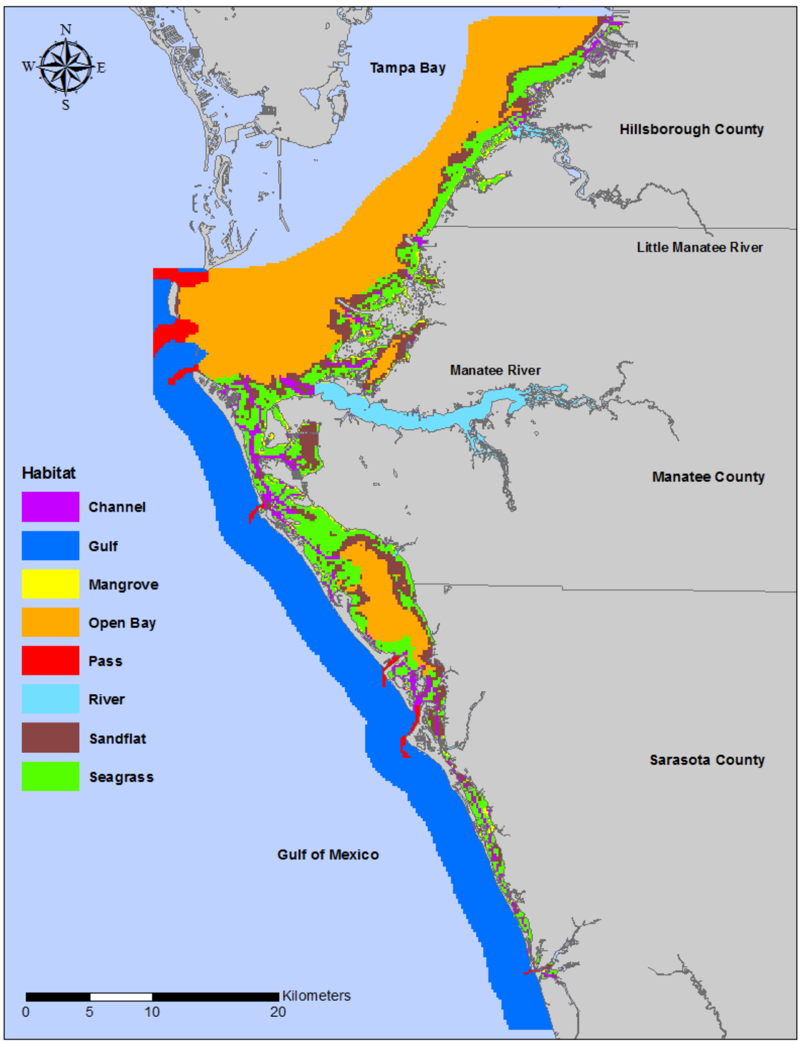

Figure 1. 2013 bottlenose dolphin habitat map covering the extent of the SDRP study area. Gray areas represent land.

Dolphin Sightings

In total, 257 sightings were recorded during 2013 photographic surveys for the 10 dolphins used as focal animals for this project. Since many of these points are very close in proximity or overlap, all sighting points were given the same color scheme (Figure 2). Nearly half of all dolphin sightings were observed in the Channel habitat, while no sightings were recorded in Mangrove and only one in River (Table 2). Almost all dolphin sightings occurred in estuarine waters, with only 16 sightings recorded in Gulf (Table 2). Though an equal sex ratio was used for these sample data, the five females were sighted a total of 146 times, while the five males were observed 111 times. For five of the primary habitat types, females were observed more than males (Table 2). However, males were observed more than females in Open Bay and River (Table 2).

Table 2. Total number of times all 10 focal dolphins, the five females and the five males were observed in each primary habitat type during 2013 photographic surveys.

Habitat Type	Total # of Sightings	# of Female Sightings	# of Male Sightings
Channel	121	70	51
Gulf	16	10	6
Mangrove	0	0	0
Open Bay	16	2	14
Pass	10	9	1
River	1	0	1
Sandflat	57	34	23
Seagrass	36	21	15

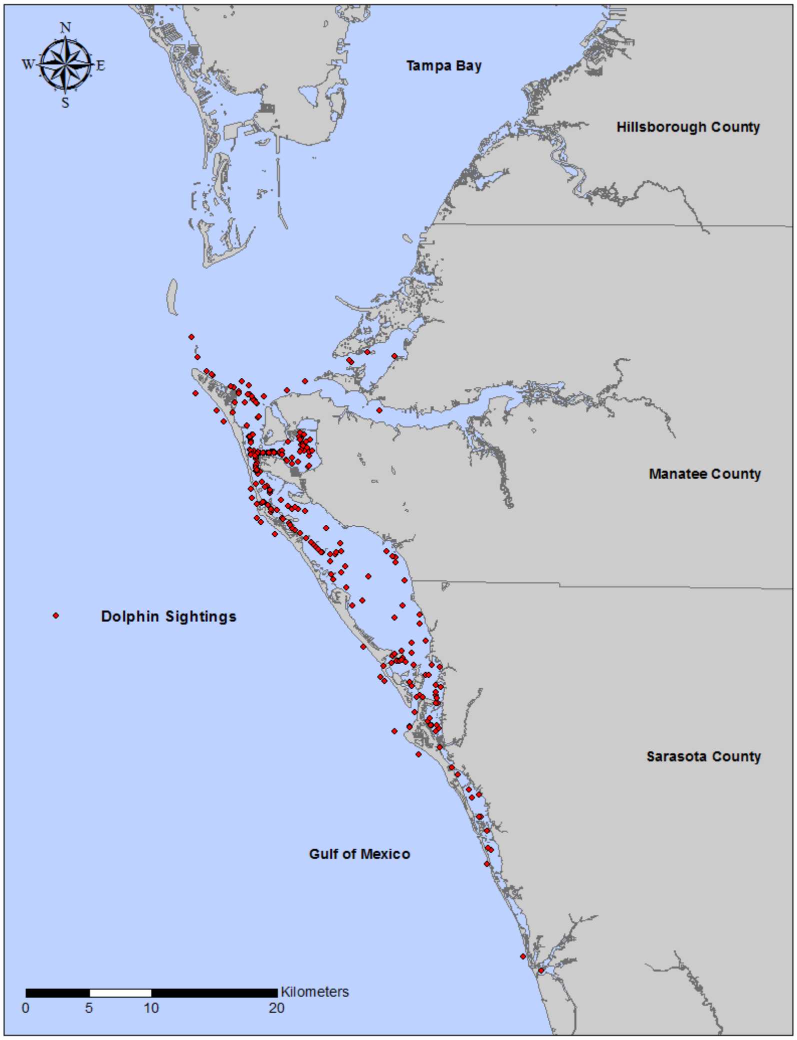

Figure 2. 2013 photographic survey locations for 10 bottlenose dolphins studied by SDRP. Gray areas represent land.

Cost Surface

The mainland shoreline and the shorelines of the numerous barrier islands within the study area contain a mix of natural and hardened features. Many stretches of the natural shoreline have been converted into seawalls to reduce erosion or allow the construction of channels and canals. The ICW is the most notable major channel within the study area, which runs in a north-south direction behind the barrier islands. Other major channels recognized by the FWC in this region include the seven passes identified in the habitat map, the Manatee and Little Manatee River channels, and the Tampa Bay shipping lane, which is the channel that runs along the northern edge of the study area (Figure 3). This shipping lane has the deepest waters within the study area, with depths usually exceeding 20 meters. Though the Gulf and Open Bay habitats are generally deep, much of the study area is very shallow. The average depth of the study area is only 4.10 meters.

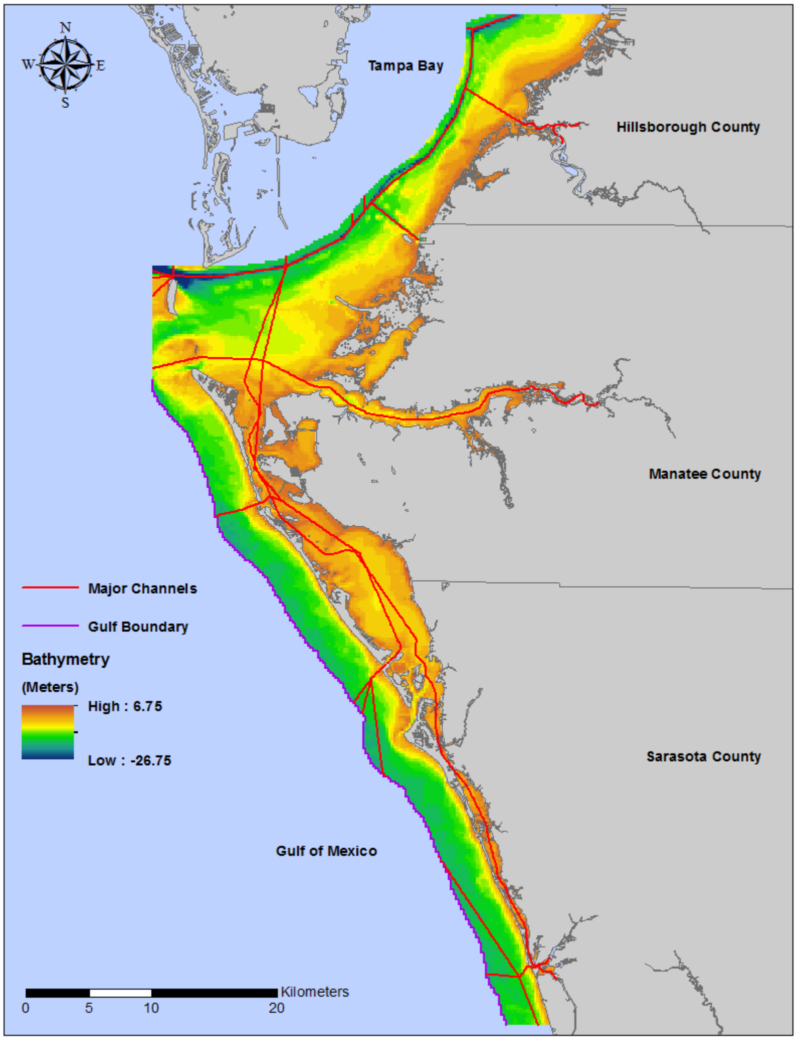

Figure 3. Map of the four inputs used to generate the bottlenose dolphin movement cost surface: bathymetry, major channels, the shoreline and a Gulf of Mexico boundary two miles offshore. Gray areas represent land.

Based on the cost surface generated by the geoprocessing model using equal weightings, Mangrove has the highest mean cost of any primary habitat type, while Open Bay has the lowest mean cost value (Table 3). Channel and River have similarly high mean costs, while Pass and Gulf have similarly low mean costs (Table 3). These results are the same for the cost surface generated using different weightings, though the mean costs of each habitat differ between the two cost surfaces (Table 4). For both cost surfaces, the mean cost of each habitat is different (Tables 3 and 4), but Gulf and Open Bay are unique because they have large expanses represented by the minimal cost value (Figures 4 and 5). The cost surfaces do not have the same range of costs, as the surface generated using different weightings has a slightly higher maximum cost than the surface generated using equal weightings (Figures 4 and 5). Due to their orientation with respect to the major channels, shoreline and Gulf of Mexico boundary, each habitat has a large range of cost values. Habitat map cells with a high cost value have a shallow depth, are close to major channels, close to the shoreline and/or close to the Gulf of Mexico boundary. Cells with a low cost value are deeper and/or further from these feature classes.

Table 3. Minimum, maximum and mean cost values for each primary habitat type found within the SDRP study area. Values generated using equal weightings for the four inputs.

Habitat Type	Min. Cost Value	Max. Cost Value	Mean Cost Value
Channel	10.0	72.5	46.39
Gulf	19.0	67.5	24.98
Mangrove	32.5	72.5	47.33
Open Bay	10.0	52.5	15.17
Pass	10.0	72.5	21.35
River	10.0	72.5	46.69
Sandflat	15.0	72.5	31.61
Seagrass	20.0	72.5	38.68

Table 4. Minimum, maximum and mean cost values for each primary habitat type found within the SDRP study area. Values generated using different weightings for the four inputs.

Habitat Type	Min. Cost Value	Max. Cost Value	Mean Cost Value
Channel	10.0	77.0	51.51
Gulf	10.0	71.0	23.65
Mangrove	37.0	77.0	54.24
Open Bay	10.0	53.0	14.40
Pass	10.0	77.0	21.38
River	10.0	77.0	50.71
Sandflat	16.0	77.0	34.85
Seagrass	22.0	77.0	42.90

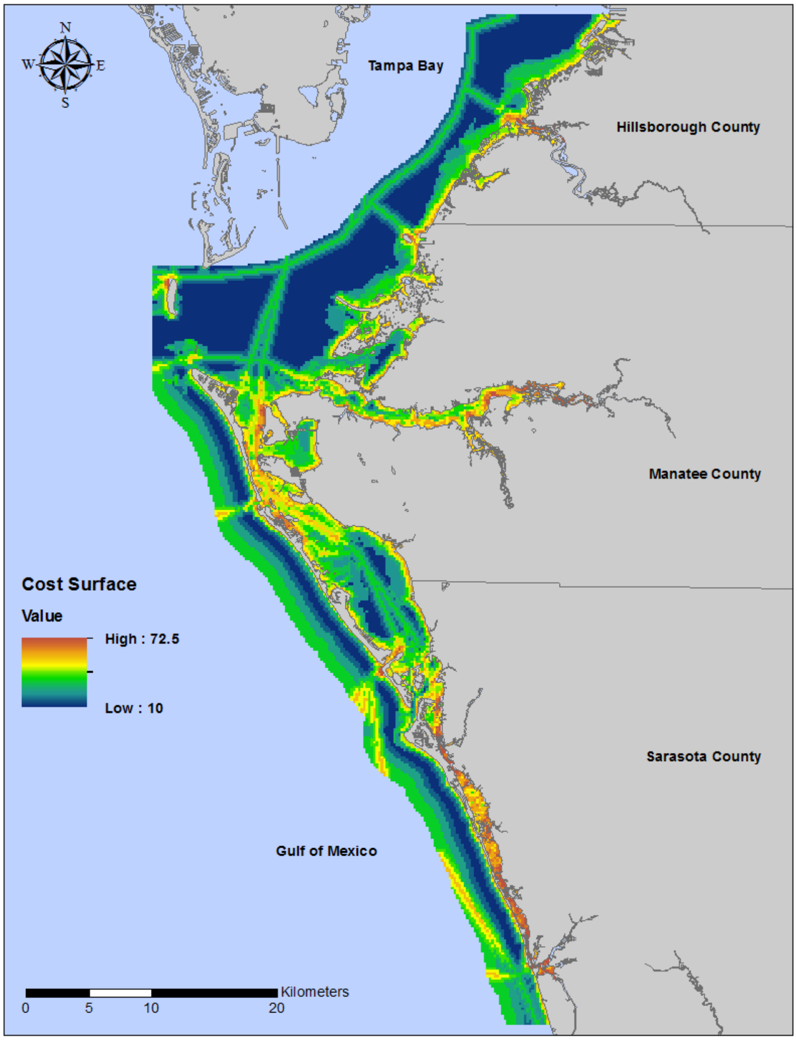

Figure 4. Map of the bottlenose dolphin movement cost surface covering the extent of the SDRP study area. Gray areas represent land. Surface generated using equal weightings for the four inputs.

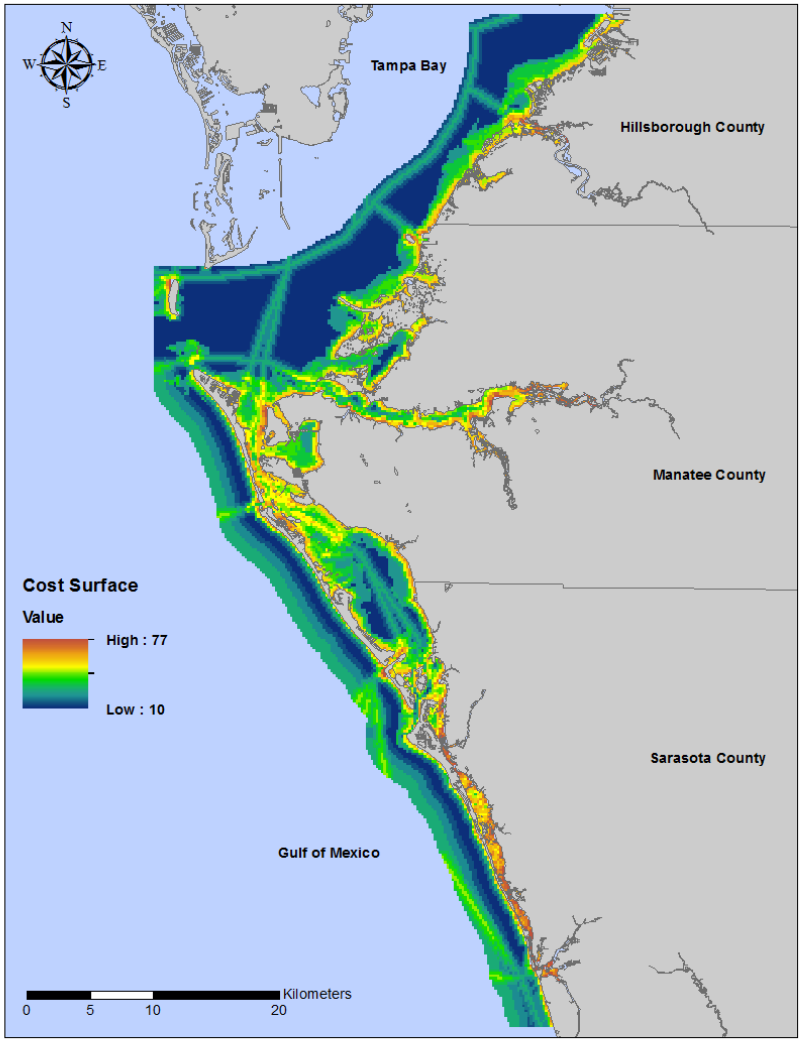

Figure 5. Map of the bottlenose dolphin movement cost surface covering the extent of the SDRP study area. Gray areas represent land. Surface generated using different weightings for the four inputs.

Discussion

Habitat Map and Cost Analysis

The primary focus of this project was to conduct a cost analysis of the SDRP study area to determine if certain primary habitat types are more costly or beneficial than others to dolphin movement. Bathymetry, distance to major channels, distance to the shoreline and distance to a Gulf of Mexico boundary were used to generate the cost surface. However, other environmental parameters such as prey availability and predator abundance were not included in the analysis due to data deficiency. It is important to recognize that the habitats in this region are constantly subject to change via natural or anthropogenic events. Currently, Seagrass does have considerably more area than Sandflat (Table 1). However, it is possible that shallow and alongshore seagrass beds could be converted into sandflats due to boat propeller damage or smothering by sediment deposits from surface runoff. Mangrove represents less than five percent of the study area (Table 1), and this number is likely to decline as mangrove forests are removed due to ongoing coastal development. On the other hand, it is possible that Channel habitat could increase if additional private canals and other navigable waterways are created to accommodate more recreational and commercial boat traffic. This could have several implications for dolphins. As previous research has shown, dredging to modify the shoreline and seafloor can cause bottlenose dolphins to alter their patterns of attendance in localized areas, even if the dolphins have learned to tolerate anthropogenic disturbances (Pirotta et al., 2013). Moreover, resident dolphins have been shown to alter their behavior, such as increasing swimming speed, in response to approaching or even passing vessels (Nowacek et al, 2001). Many aspects of dolphin life history, such as feeding or travelling, are directly influenced by habitat availability. If significant habitat alterations occur within this region, it is possible that resident dolphins could experience disruptions to their natural behaviors.

I hypothesized that the Channel and Mangrove habitats would have the highest mean cost values, while Gulf and Open Bay would have the lowest. Based on the results generated by the geoprocessing model, this hypothesis was not supported. Channel and Mangrove did have the highest mean costs as expected (Tables 3 and 4). Both habitats are usually close to or border the shoreline, mangrove forests grow in very shallow water, and major channels are what define the Channel habitat. These characteristics are what led to these two habitats having such high mean costs. However, while Open Bay did have the lowest mean cost of any habitat type, Pass had a slightly lower mean cost than Gulf (Tables 3 and 4), which was surprising given the proximity of passes to the shoreline and that major channels cut through passes. Still, all three habitats do share the common trait of very deep water. This is the primary reason that they have the lowest mean costs.

I also hypothesized that resident bottlenose dolphins will use habitats with lower mean costs more frequently than habitats with higher mean costs. Based on the 2013 SDRP photographic survey data for 10 dolphins and previous research on dolphin habitat use in this region, this hypothesis was not supported. The results of the cost analysis would suggest that dolphins prefer the Gulf, Open Bay and Pass habitats and avoid Channel and Mangrove. While dolphins likely minimize their time spent swimming in mangrove forests due to the risk of becoming trapped or beached, previous studies have shown that they actually have a preference for using dredged channels to move between areas (Irvine et al., 1981; Scott et al., 1990). The shallowness of many parts of the study area restricts vertical movement (Irvine et al., 1981), and these waterways represent the path of least resistance for dolphins behind the barrier islands. Though it is a small subsample, the photographic survey data support this information, as Channel had the greatest number of recorded observations of all primary habitats (Table 2). While individual dolphins do appear to exhibit strong habitat selection, research has shown that at the population level these dolphins do not use any habitat type disproportionately to its availability (i.e. no preference for a particular habitat type) (Gannon et al., 2008). Though the four environmental inputs used to generate the cost surface do affect dolphin movement, prey availability, foraging behavior and predation risk may be more important factors influencing dolphin habitat use (McHugh et al., 2011).

Policy and Conservation

Sarasota Bay dolphins occupy a home range where they are frequently exposed to anthropogenic interactions. There are many stakeholders in this region that are either concerned with, or contribute to, these human-dolphin interactions. These include the numerous tourists that visit Florida, recreational boaters, recreational and commercial fishermen, marine life tours that actively search for wildlife, rental companies, watersport businesses (e.g. parasailing), the residents of these three counties, and scientific researchers. Regardless of intent, all of these groups may have an impact on or an interest in resident dolphins. While the Marine Mammal Protection Act (MMPA) of 1972 affords bottlenose dolphins federal protection, the FWC is responsible for the enforcement of this legislation in state waters. The FWC is a state government agency charged with managing the fish and wildlife resources, regulating fish and wildlife, and enforcing related laws in the state of Florida (FWC, 2014). The MMPA is a federal act that established a moratorium on the take of marine mammals in the United States (Cicin-Sain and Knecht, 2000).

Some human interactions with wild dolphins have the potential to injure or kill dolphins, or they may contribute to the development of unnatural foraging behaviors such as begging, scavenging and depredation (when dolphins take and feed on bait or catch from fishing lines) (McHugh, 2014). As such, human-dolphin interactions are a problem of increasing concern for management and conservation of nearshore bottlenose dolphins (McHugh, 2014). Provisioning, entanglement in fishing gear, ingestion of marine debris, noise pollution and boat strikes are all examples of human-dolphin interactions. Unfortunately, collisions with vessels continue to be a problem for Sarasota Bay dolphins; the summer of 2012 saw a record number of documented boat strikes (Barleycorn, 2013). For example, when dolphins chase fish into shallow water, they are at greater risk of strikes from flats boats. Furthermore, boats create a noisy environment and can potentially interfere with echolocation or vocalizations dolphins use to communicate. In addition, provisioning can make dolphins reliant on food offered by humans and decrease their ability to survive in the wild (Cicin-Sain and Knecht, 2000). There have also been numerous documented cases by the SDRP of dolphins becoming entangled in fishing line or ingesting hooks, both of which have been fatal on occasions.

SDRP is a model program for addressing dolphin conservation issues. They use archived data along with current observational data to identify trends will help the National Oceanic and Atmospheric Administration (NOAA) to more appropriately distribute its limited resources for mitigating human-dolphin interactions (Wells, 2013). While science is rarely an end in itself for marine mammal conservation, it plays a central role by providing the knowledge needed to address and solve problems like human-dolphin interactions (Hoelzel, 2002). There are several strategies that have already been employed to mitigate these interactions, including the “Don’t Feed Wild Dolphins” public service announcement by SDRP, NOAA, and other partners, as well as the distribution of handouts to local businesses and education partners, press releases and use of mobile applications. These media help to spread the word about limiting human-dolphin interactions. One such example is the “Dolphin Friendly Fishing and Viewing Tips” handout published by the SDRP. In order to reduce marine debris, recycling bins created for the safe disposal of fishing line have been distributed across the region. While marine mammal watching can be considered a conservation strategy because it directs the emphasis away from consumptive use, it remains a human-dolphin interaction that presents potential disturbance to the animals (Bejder et al., 2006). As such, the National Marine Fisheries Service (NMFS) recommends staying at least 50 yards away from dolphins and slowing down when they are in the area (Barleycorn, 2013).

Some of the solutions I recommend in order to mitigate human-dolphin interactions include stricter enforcement by the FWC and the NOAA Fisheries Southeast Enforcement

Division, public education, outreach and training, and promoting the avoidance of wild bottlenose dolphins. During their studies of a male dolphin known for begging, the SDRP researchers found that having law enforcement on hand was the most effective means of getting people to stop interacting with him (Wells et al., 2013). If more officers are present on the water, boaters are less likely to approach and interact with dolphins. Enforcement efforts should be especially increased during peak tourist seasons, and harsher fines could be used as penalties for violating the MMPA. In addition, facilities like the Mote Marine Laboratory and other aquariums should continue to be used as centers to promote awareness through education, outreach and training. Furthermore, boaters should attempt to use marked channels for travel as often as possible. Dolphins are less likely to get injured when boats are concentrated in limited areas. Florida manatee (*Trichechus manatus latirostris*) slow zones could even be expanded in order to accommodate bottlenose dolphins as an ecosystem management strategy, or speed limits in channels could be lowered to allow dolphins more reaction time. There are numerous proposed solutions to ameliorate this problem, but determining which strategy is the most effective will require time and effort, including additional research to assess the impacts of each strategy. As the human-use of coastal waterways in the Sarasota area continues to grow, so does the need to monitor and reduce the number of human-dolphin interactions.

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References

Barleycorn, A. “Sarasota Bay boat strikes in 2012.” *Nicks ‘n’ Notches: Annual Summary of the Activities and Findings of the Sarasota Dolphin Research Program* (Jan. 2013): 12. Print.

Barros, N. B. and R. S. Wells. 1998. Prey and feeding patterns of resident bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. Journal of Mammalogy **79**: 1045-1059.

Bejder, L., A. Samuels, H. Whitehead, N. Gales, J. Mann, R. Connor, M. Heithaus, J. Watson-Capps, C. Flaherty and M. Krützen. 2006. Decline in relative abundance of bottlenose dolphins exposed to long-term disturbance. Conservation Biology **20**: 1791-1798.

Cicin-Sain, B. and R. W. Knecht. 2000. *The Future of U.S. Ocean Policy: Choices for the New Century*. Island Press, Washington, D.C.

Florida Fish and Wildlife Conservation Commission. Web. 7 March 2014. <http://myfwc.com/>

Gannon, D., A. Friedlaender, J. Gannon, E. B. McCabe, J. Allen, S. Hoffman and R. S. Wells. 2008. Comparing patterns of habitat selection at the levels of the population and the individual. *Publications – Sarasota Dolphin Research Program*. Web. 7 March 2014. < http://sarasotadolphin.org/2008/01/02/comparing-patterns-of-habitat-selection-at-the-levels-of-the-population-and-the-individual/>

Irvine, A. B., M. D. Scott, R. S. Wells and J. H. Kaufmann. 1981. Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. Fishery Bulletin **79**: 671-688.

Marine Mammal Biology: An Evolutionary Approach. 2002. Ed. R. Hoelzel. Blackwell Publishing, Malden, MA.

McCabe, E. B. and D. Gannon. 2005. Habitat quality and prey availability for bottlenose dolphins. *Publications – Sarasota Dolphin Research Program*. Web. 7 March 2014. <http://sarasotadolphin.org/2005/01/14/habitat-quality-and-prey-availability-for-bottlenose-dolphins-2/>

McHugh, K. “Ongoing human interaction research in Sarasota Bay.” *Nicks ‘n’ Notches: Annual Summary of the Activities and Findings of the Sarasota Dolphin Research Program* (Jan. 2014): 9. Print.

McHugh, K. A., J. B. Allen, A. A. Barleycorn and R. S. Wells. 2011. Natal philopatry, ranging behavior, and habitat selection of juvenile bottlenose dolphins in Sarasota Bay, Florida. Journal of Mammalogy **92**: 1298-1313.

Nicks ‘n’ Notches: Annual Summary of the Activities and Findings of the Sarasota Dolphin

Research Program (Jan. 2014): 2-3. Print.

Nowacek, S. M., R. S. Wells and A. R. Solow. 2001. Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. Marine Mammal Science **17**: 673-688.

Pirotta, E., B. E. Laesser, A. Hardaker, N. Riddoch, M. Marcoux and D. Lusseau. 2013. Dredging displaces bottlenose dolphins from an urbanised foraging patch. Marine Pollution Bulletin **74**: 396-402.

Sarasota Dolphin Research Program. Web. 7 March 2014. < http://sarasotadolphin.org/>

Scott, M. D., R. S. Wells and A. B. Irvine. "A Long-Term Study of Bottlenose Dolphins on the West coast of Florida." *The Bottlenose Dolphin*, Eds. S. Leatherwood and R. R. Reeves: Academic Press, San Diego, 1990. 235-244.

Wells, R. S. "Social Structure and Life History of Bottlenose Dolphins Near Sarasota Bay, Florida: Insights from Four Decades and Five Generations." *Primates and Cetaceans*, Eds. J. Yamagiwa and L. Karczmarski: Springer Japan, 2014. 149-172.

Wells, R. S. 2013. What is the value of a unique, long-term dolphin research and conservation program? *Publications – Sarasota Dolphin Research Program*. Web. 7 March 2014. < http://sarasotadolphin.org/2013/01/11/what-is-the-value-of-a-unique-long-term-dolphin-research-and-conservation-program/>

Wells, R. S., A. B. Irvine and M. D. Scott. "The Social Ecology of Inshore Odontocetes." *Cetacean Behavior*, Ed. L. M. Herman: Wiley-Intersci, N.Y., 1980. 263-317.

Wells, R. S., McHugh, K., Lovewell, G. and Slimak, N. 2013. Beggar – A human interaction icon meets an untimely end. *Publications – Sarasota Dolphin Research Program*. Web. 7 March 2014. < http://sarasotadolphin.org/2013/01/26/beggar-a-human-interaction-icon-meets-an-untimely-end/>

Appendix

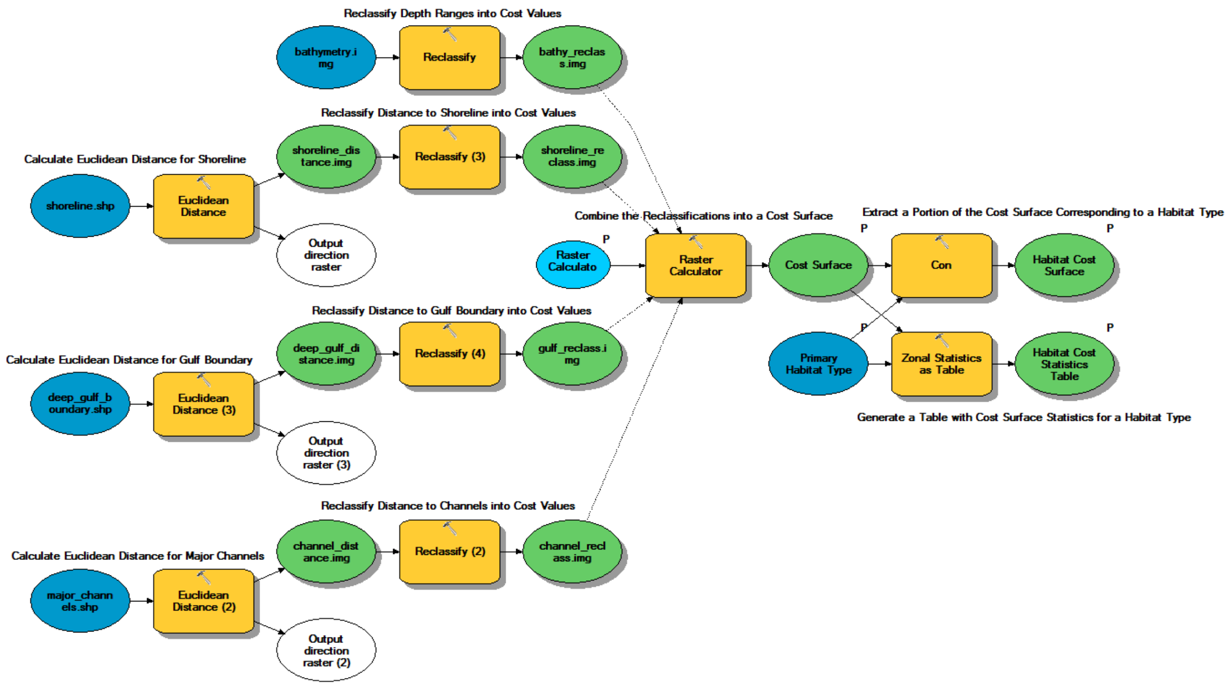

Figure 6. Geoprocessing model used to generate a bottlenose dolphin movement cost surface for the SDRP study area and a table with cost value statistics for a user-selected primary habitat type.

Geoprocessing Model Python Script

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# Habitat_Costs_Tool_Script.py
# Created on: 2014-02-24 19:06:18.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: Habitat_Costs_Tool_Script <Raster_Calculator_Expression> <Cost_Surface>
<Primary_Habitat_Type> <Habitat_Cost_Surface> <Habitat_Cost_Statistics_Table>
# Description:
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("spatial")

# Set Geoprocessing environments
arcpy.env.scratchWorkspace = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Scratch"
arcpy.env.outputCoordinateSystem =
"PROJCS['NAD_1983_UTM_Zone_17N',GEOGCS['GCS_North_American_1983',DATUM['D
_North_American_1983',SPHEROID['GRS_1980',6378137.0,298.257222101]],PRIMEM['Gree
nwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Transverse_Mercator'],PAR
AMETER['False_Easting',500000.0],PARAMETER['False_Northing',0.0],PARAMETER['Centr
al_Meridian',-
81.0],PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_Of_Origin',0.0],UNIT['Me
ter',1.0]]"
arcpy.env.snapRaster = ""
arcpy.env.extent = "324500.999996 2995113 362700.999996 3075513"
arcpy.env.cellSize = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\bathymetry.img"
arcpy.env.geographicTransformations = ""
arcpy.env.mask = "Habitat Map"
arcpy.env.workspace = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data"

# Script arguments
Raster_Calculator_Expression = arcpy.GetParameterAsText(0)
if Raster_Calculator_Expression == '#' or not Raster_Calculator_Expression:
    Raster_Calculator_Expression = "(0.25*\"%bathy_reclass.img%\") +
(0.25*\"%channel_reclass.img%\") + (0.25*\"%shoreline_reclass.img%\") +
(0.25*\"%gulf_reclass.img%\")" # provide a default value if unspecified

Cost_Surface = arcpy.GetParameterAsText(1)
if Cost_Surface == '#' or not Cost_Surface:
    Cost_Surface = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\cost_surface.img" #
provide a default value if unspecified
```

```
Primary_Habitat_Type = arcpy.GetParameterAsText(2)
if Primary_Habitat_Type == '#' or not Primary_Habitat_Type:
   Primary_Habitat_Type = "Channel" # provide a default value if unspecified

Habitat_Cost_Surface = arcpy.GetParameterAsText(3)
if Habitat_Cost_Surface == '#' or not Habitat_Cost_Surface:
   Habitat_Cost_Surface = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\habitat_cost_surface.img" # provide a default value if
unspecified

Habitat_Cost_Statistics_Table = arcpy.GetParameterAsText(4)
if Habitat_Cost_Statistics_Table == '#' or not Habitat_Cost_Statistics_Table:
   Habitat_Cost_Statistics_Table = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\habitat_zonal_stats.dbf" # provide a default value if
unspecified

# Local variables:
bathymetry_img = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\bathymetry.img"
major_channels_shp = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\major_channels.shp"
deep_gulf_boundary_shp = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\deep_gulf_boundary.shp"
shoreline_shp = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\shoreline.shp"
shoreline_distance_img = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\shoreline_distance.img"
Output_direction_raster = ""
channel_distance_img = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\channel_distance.img"
Output_direction_raster__2_ = ""
bathy_reclass_img = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\bathy_reclass.img"
channel_reclass_img = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\channel_reclass.img"
shoreline_reclass_img = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\shoreline_reclass.img"
deep_gulf_distance_img = "X:\\Master's
Project\\GIS_Data\\Cost_Analysis\\Data\\deep_gulf_distance.img"
Output_direction_raster__3_ = ""
gulf_reclass_img = "X:\\Master's Project\\GIS_Data\\Cost_Analysis\\Data\\gulf_reclass.img"

# Process: Euclidean Distance
arcpy.gp.EucDistance_sa(shoreline_shp, shoreline_distance_img, "", "200",
Output_direction_raster)

# Process: Euclidean Distance (2)
```

```
arcpy.gp.EucDistance_sa(major_channels_shp, channel_distance_img, "", "200",
Output_direction_raster__2_)

# Process: Euclidean Distance (3)
arcpy.gp.EucDistance_sa(deep_gulf_boundary_shp, deep_gulf_distance_img, "", "200",
Output_direction_raster__3_)

# Process: Reclassify
arcpy.gp.Reclassify_sa(bathymetry_img, "Value", "-26.75 -3 10;-2.9999989999999999 -2 50;-
1.9999990000000001 -1 80;-0.99999899999999997 6.75 100", bathy_reclass_img, "DATA")

# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(channel_distance_img, "Value", "0 199.999999 90;200 399.999999
60;400 599.999999 30;600 9808.16015625 10", channel_reclass_img, "DATA")

# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(deep_gulf_distance_img, "Value", "0 999.999999 90;1000
1599.9999989999999 60;1600 1999.9999989999999 30;2000 46923.33984375 10",
gulf_reclass_img, "DATA")

# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(shoreline_distance_img, "Value", "0 199.999999 90;200 399.999999
60;400 599.999999 30;600 7071.0678710938 10", shoreline_reclass_img, "DATA")

# Process: Raster Calculator
arcpy.gp.RasterCalculator_sa("%Raster Calculator Expression%", Cost_Surface)

# Process: Con
arcpy.gp.Con_sa(Primary_Habitat_Type, Cost_Surface, Habitat_Cost_Surface, "", "")

# Process: Zonal Statistics as Table
arcpy.gp.ZonalStatisticsAsTable_sa(Primary_Habitat_Type, "Value", Cost_Surface,
Habitat_Cost_Statistics_Table, "DATA", "MIN_MAX_MEAN")
```