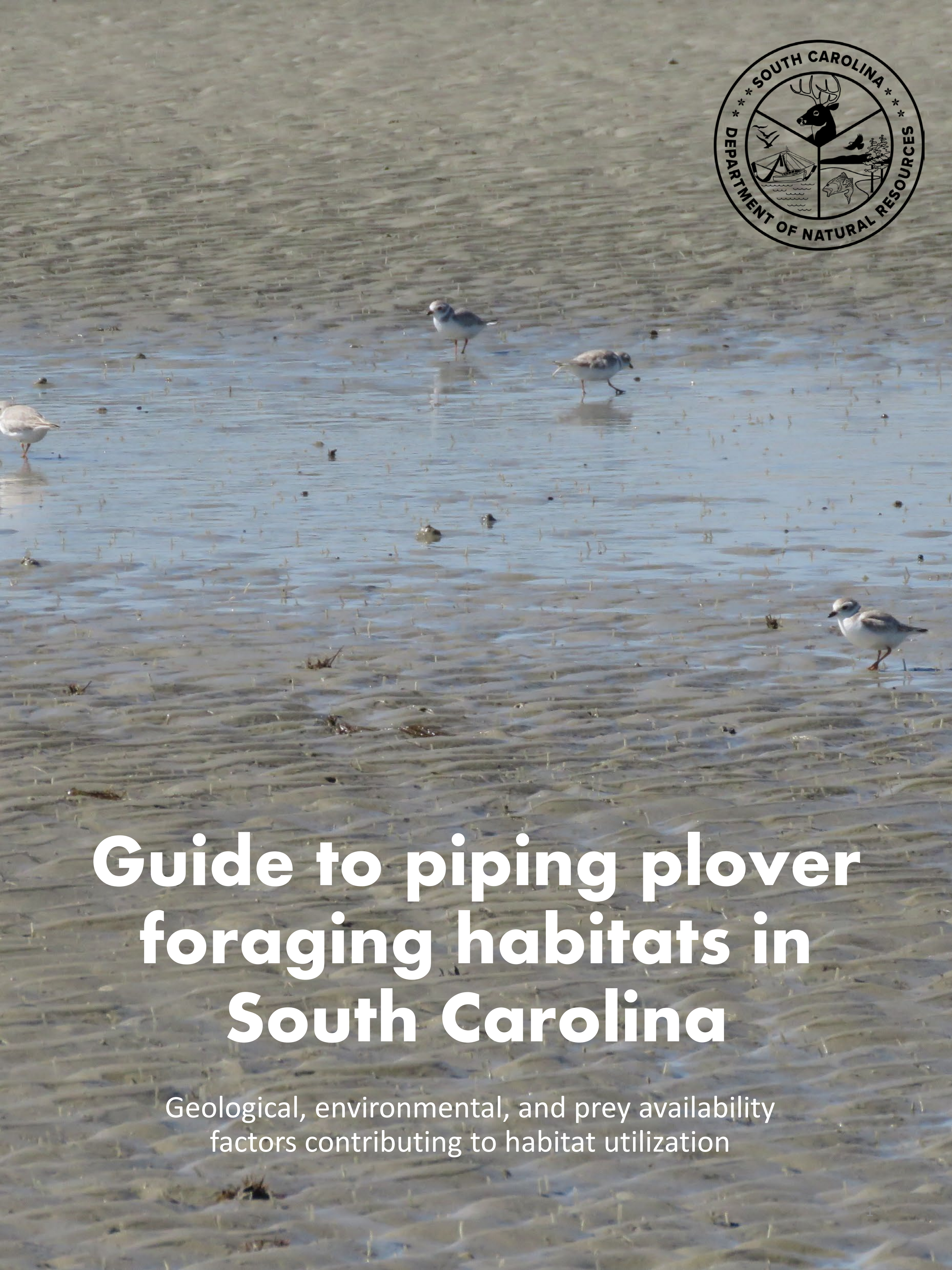

South Carolina Department of Natural Resources

Guide to piping plover foraging habitats in South Carolina

Geological, environmental, and prey availability factors contributing to habitat utilization

This effort was supported by a NERR Science Collaborative Catalyst grant (*Identifying optimal foraging habitat characteristics to inform piping plover and red knot habitat management*, 2020-2022). It is intended for use by state and federal agency staff to assist in coastal permit application review, including the assessment of impacts and recommendation of alternatives to reduce impacts to important shorebird foraging habitats.

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Technical Report No. 113
2023

Cover photo: M. Chaplin, USFWS. Piping plovers foraging on Harbor Island's inlet-facing beach flats. Tubes of the parchment worm, *Kimbergonuphis microcephala,* are abundant.

Citation: Tweel, A.W., D.M. Sanger, M.K. Chaplin. Guide to piping plover foraging habitats in South Carolina: Geological, environmental, and prey availability factors contributing to habitat utilization. South Carolina Department of Natural Resources Marine Resources Division. Charleston, SC. Technical Report No. 113. 17 p.

Introduction

Shorebird populations are declining globally in the face of sea level rise, increasing coastal development, and shoreline modifications. The piping plover (*Charadrius melodus*), red knot (*Calidris canutus*) and other shorebird species have exhibited population declines in recent years. The piping plover is a federally listed species that spends most of the year in its wintering range, including intertidal habitats in South Carolina. Recent research has established linkages between benthic prey abundance and foraging activity along South Carolina beaches; however, most of these projects focused on determining impacts from shoreline modification, rather than quantifying habitat characteristics. Identifying characteristics associated with optimal foraging habitat can aid state and federal permitting and habitat management activities in areas these shorebirds inhabit.

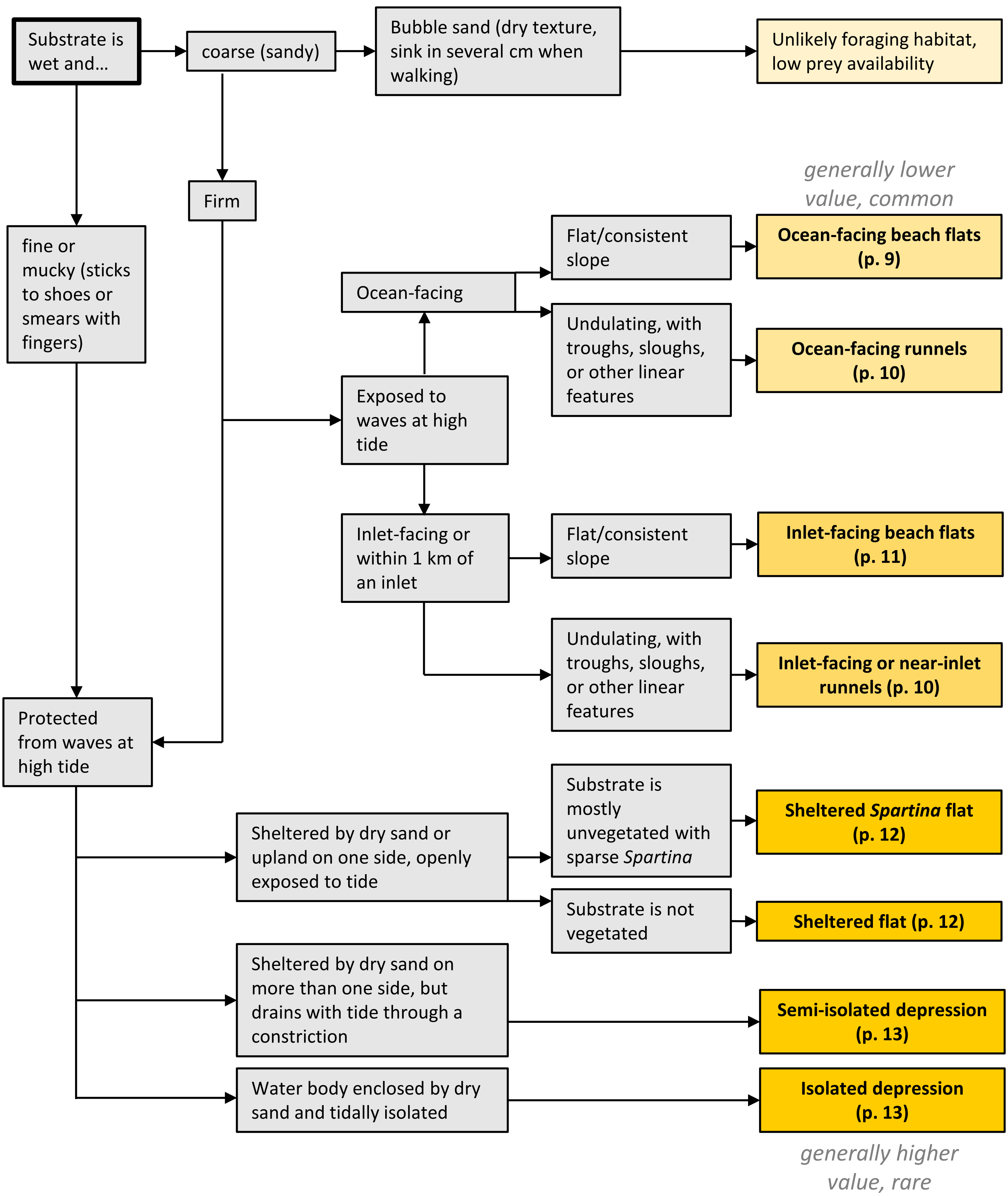
A project team at the SC Department of Natural Resources worked with the ACE NERR, the U.S. Fish and Wildlife Service, and other stakeholder groups to develop a habitat assessment tool for the piping plover. This easy-to-use tool was derived from new data collections in areas of high foraging activity, application of new genetic tools to distinguish preferred prey in fecal samples, and reanalysis of a decade (2011-2021) of sampling data collected along the SC coast. The tool allows for identification of important habitats and provides the user an understanding of what is unique about each of these areas. Information was collected to further knowledge of red knot foraging areas, but more work is needed before there is sufficient information to develop a tool.

To develop this tool, a variety of piping plover foraging habitat types were sampled for benthic community composition, sediment characteristics, and elevation. Red knot foraging areas were also sampled, but this species has not been studied as much and as such does not have the larger historical database to leverage for a meta-analysis. Red knot dietary preferences prior to horseshoe crab spawning season are not well known. These datasets were analyzed in the context of additional available data such as foraging bird density, diet preferences, and biomass of prey items. Combined, these metrics were used to assess habitat importance and what makes each area unique from a foraging perspective. Additional habitats such as wrack lines and exposed marsh relics may also provide valuable shorebird foraging opportunities, but their utilization as foraging habitats and prey densities at the landscape scale are not well understood.

Foraging habitats range from low elevation, amphipod-dominated sites such as inlet-facing beach flats to muddy sheltered depressions that are rich in polychaete worms. The relative abundance of each habitat type was also considered, such that rare habitats (e.g., isolated depressions) warrant additional conservation action as there are only select places that they can form. Tidal availability was another important consideration, as low elevation sites can provide high densities of desired prey species, but these areas may only be available for foraging 20% or less of the time. Higher elevation sites offer more foraging opportunity and as such provide more valuable habitat from a foraging perspective. The coastal permitting process can utilize this and other types of information generated through this effort in considering potential foraging habitat impacts that may result from future projects.

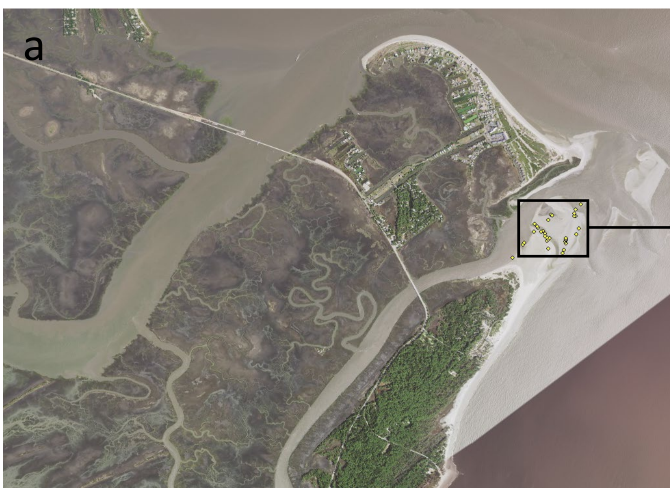
Key to intertidal foraging habitat types

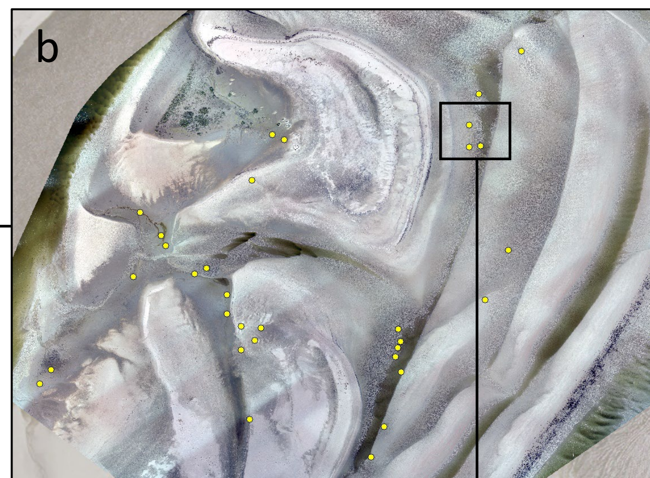
Best utilized for imagery or site visits at or near low tide



Once a habitat type is identified, habitat quality indicators may be of use when working within a given habitat or area, or when comparing multiple habitats of the same category (e.g., two inlet-facing beach flats). The table below indicates characteristics associated with higher or lower value habitats. Values were determined using foraging bird density and prey availability data. Gray shading indicates binary characteristics that do not have intermediate values.

Foraging habitat quality indicators											
Lower value	1	2	3	4	5	6	7	8	9	10	***Higher value***
All habitats:											
Only one habitat in 1 mile											**Multiple habitats in 1 mile (p. 6)**
Dry looking at low tide											**Water film/glossy at low tide (p. 7)**
No visible bird activity											**Droppings, footprints (p. 6, 14)**
No visible infauna											**Worm castings, pellets, or tubes (p. 6)**
Ocean or inlet-facing habitats only:											
Flat surface											**Rippled surface (p. 6, 7)**
High slope (>3%)											**Gentle slope (<1.5%)**
North side of inlet											**South side of inlet (p. 6)**
Sheltered habitats only:											
Mostly vegetated											**Sparse or absent vegetation (p. 8)**





Examples of foraging habitat selection across multiple spatial scales. Yellow dots indicate foraging sightings from Hunting Island surveys (2020-2021 season). Generally, the ends of barrier islands and inlet-facing beaches are the most desirable foraging areas (a). Within those areas, foraging occurs in specific habitats such as sheltered flats or runnels (b). At a fine scale, the edges of wet sediments and small pools concentrate foraging birds (c, photo: M. Chaplin).

Multiple habitats that occur within a relatively small area, as seen in this example from Harbor and Hunting Islands, provide diverse foraging options in terms of prey resources, tidal availability, and wind exposure. The southern boundary of inlets is generally more conducive to the development of flats and other complex features as shown above, but sand spit formation can also form high quality habitats on the northern boundaries (e.g., Captain Sam's spit).

Rippled sand flats occur in areas where tidal currents run back and forth along a gently sloping flat, often near inlets. These are associated with greater prey abundances and bird foraging activity than smooth flats with similar grain and elevation characteristics (Hayes and Michel 2008).

Examples of benthic infauna signatures seen on sheltered and inlet-facing flats. Tubes of the parchment worm, *Kimbergonuphis microcephala,* and a foraging piping plover on Harbor Island (a, photo: M. Chaplin). Acorn worm (*Balanoglossus* or *Saccoglossus*) burrows are good indicators of high benthic infauna abundance on sheltered flats (b). These occur in pairs as ends of a U-shaped burrow, with the divots indicating the intake side and the mound indicating the castings. A variety of types of worm castings are often seen in sheltered mudflats (c).

Rippled flats, particularly those with troughs filled with organic material and fecal pellets as seen here (top), are often associated with high shorebird foraging activity (Harbor Island 2017). Similarly, sand and fine material flats that maintain a sheen of water at low tide are often popular with foraging shorebirds (bottom, Deveaux Bank 2017). These wet areas may concentrate infauna seeking to avoid desiccation at low tide (Martin 2013). In addition to other shorebird species visible in the photo, two piping plovers are indicated by the black arrows.

Examples of *Spartina* flats utilized by foraging piping plovers on Deveaux Bank (top, 2021) and Harbor Island (bottom, 2017). Both flats are characterized by relatively fine substrate (5% silt/clay) and short/sparse vegetation. Both mudflats were relatively small (50-80 m) with vegetation cover less than 50%. Use of these habitats by foraging piping plovers is rare, with few sites on record. However, foraging bird density at these sites was among the highest of all sites.

Ocean-facing beach flats

These beach flats develop where wave energy is moderate or high, on the ocean-facing edge of barrier islands. Compared to inlet-facing flats, these flats are characterized by higher energy waves. This results in coarser substrate and often greater beach slope, particularly on erosive beaches. These habitats are generally lower quality foraging habitat than those near inlets and as such are more frequently used by migrating rather than overwintering piping plovers who expend resources protecting the near-inlet habitats that are more desirable as overwintering territories. Wide, low-slope flats do occur, offering a greater foraging area, and these are more common on low erosion beaches. Beaches characterized by high erosion or retreating shorelines generally exhibit steeper slopes and offer less area for foraging. Tidal exposure is comparable or slightly less than inlet-facing flats (24%, 0.5 ± 0.04 m MLLW). One main difference from inlet-facing flats, however, is the near absence of prey polychaetes. Prey amphipods can be fairly abundant, but of the sandy habitats this ranks the lowest in biomass density. *Donax* clams are common but not considered a prey item. Rippled substrate texture is not common unless very near an inlet. Upright worm tubes are usually absent.

Dark shading indicates the most common characteristic of a given habitat

Beach flats: ocean-facing										
Waves	■									**Calm**
Sandy			■							**Muddy**
Low in tide frame		■								**High in tide frame**
Amphipods		■								**Worms**
Low biomass						■				**High biomass**
Low bird activity				■						**High bird activity**
Common		■								**Rare**

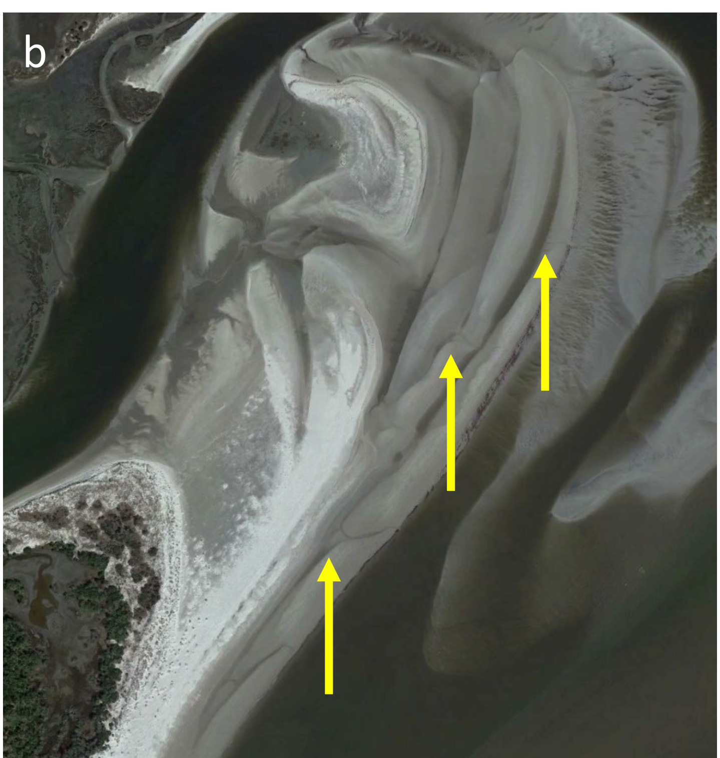
Examples of ocean-facing beach flats on Kiawah Island near Beachwalker Park (a,d). These habitats can be relatively featureless or contain small runnel or trough features that add complexity and edges for foraging, such as along Folly Beach near the county park (c). A smaller trough is visible in (d). Common prey items include a variety of sizes and species of amphipods as well as small clams and low abundances of polychaete worms, such as in this sample collected near Captain Sam's inlet in 2015 (b). The worm species present are usually too small to be considered viable prey (e.g., *Scololepis*).

Runnels: inlet and ocean-facing

These linear features can develop near inlets or along ocean-facing beaches. While the substrate is generally sandy and comparable to ocean-facing beaches, additional complexity provides more edge for foraging than a single sloping beach. Additionally, runnels often occur higher (1.45 ± 0.25 m MLLW) in the tidal frame than ocean-facing beaches and can be available for foraging over 70% of the time. Available prey items are usually haustorid amphipods, which occur in slightly greater densities (μ > 3,000 m^{-2}) than other beach habitats, and their additional time exposed and edge area also provide additional value to foraging birds. Runnels located near inlets are often more extensive and occur along a greater elevation gradient than ocean-facing runnels which are lower in elevation and often occur as single features. Rippled sand features, also observed near inlets, are associated with greater prey densities. Bird activity can be moderate along the beachfront but high near inlets, perhaps reflecting the differences in availability, prey density, and proximity to roosting or other foraging areas.

Runnels: inlet- and ocean-facing											***Shading: inlet=black, ocean=gray***
Waves				▒	■						**Calm**
Sandy		▒	■								**Muddy**
Low in tide frame							▒	■			**High in tide frame**
Amphipods	■										**Worms**
Low biomass						▒		■			**High biomass**
Low bird activity					▒	■	■				**High bird activity**
Common					▒	■					**Rare**

Runnel features can host very high densities of large haustorid amphipods, as seen in this sample from Hunting Island (a). Other infaunal items include tiny clams (a, right) and a polychaete worm species that is too small to be considered a prey item. The sample in (a) was collected near the right-most arrow in (b) at Hunting Island State Park in March 2021. The other arrows indicate a variety of shapes and elevations of runnel features. This same feature is shown from the ground (c) and contained expansive ripple features, which are often associated with greater infaunal densities.



Inlet-facing beach flats

These beach flats develop where wave energy is moderate or low, typically on the north end of barrier islands, such as the 'heel' of Hilton Head Island or most of Harbor Island. These flats can be expansive and are relatively common at the landscape scale, but are situated relatively low in the tide frame, exposed about 25% of the time (0.6 ± 0.01 m MLLW). The substrate is often fine sand and sometimes muddy sand. Silt/clay values are usually 1-3%, but are more variable than other habitats and can exceed 10% in small pockets. Tidal currents running across the flats can create a rippled texture, and these areas are associated with high densities of benthic infauna (Hayes and Michel 2008). This community is typically dominated by amphipods, especially *Acanthohaustorius* sp. (µ 0.34 mg AFDW, a measure of shell-free biomass), a desirable prey species. Rippled flats may also exhibit worm tubes projecting from the substrate, and some of the highest foraging bird densities have been documented at these areas (e.g., Harbor Island). Non-rippled flats can also provide quality foraging areas, but the prey density is usually lower and more often supports the haustorid species *Neohaustorius schmitzi* (µ 0.23 mg AFDW). The prey community in either type is dominated by amphipods, with densities exceeding 2,000 m^{-2}, but inlet-facing beach flats are also the most diverse foraging habitat, with polychaetes, pea crabs, and nemertean worms also present in pockets where finer substrates appear or where wave energy is lower. These pockets may develop behind shoreline points (e.g., Harbor Island south end) or near marsh relics (e.g., Fish Haul Beach Park on Hilton Head).

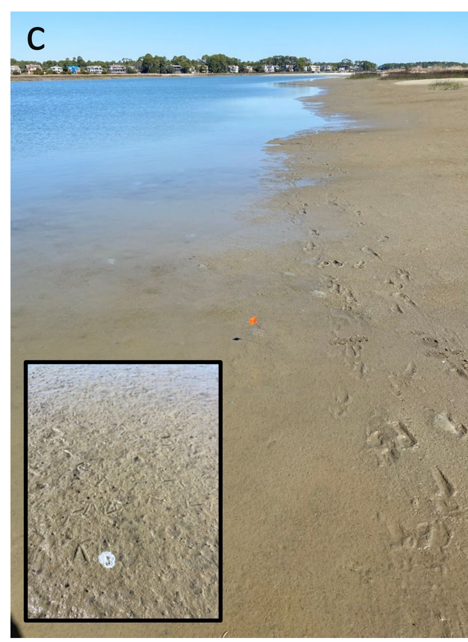
Beach flats: inlet-facing										
Waves			■	■						**Calm**
Sandy			■	■	■					**Muddy**
Low in tide frame		■								**High in tide frame**
Amphipods		■	■	■						**Worms**
Low biomass							■			**High biomass**
Low bird activity						■				**High bird activity**
Common		■								**Rare**

Inlet-facing beach flats are prevalent on Harbor Island (a) and Hilton Head Island (b). A single beach area can support multiple habitat types, including complex rippled flats (b, top, and c) and smooth, higher slope beaches (b, bottom, and c, background). Prey abundance and foraging bird density is typically higher at the rippled flats, although they are only accessible for a short time. The prey community is usually dominated by amphipods, but small clams and polychaete worms may be present.

Sheltered flats

Sheltered flats or mudflats develop where wave energy is low, often on the protected side of sand shoals, inlets, or other features that block waves. This allows silts and clays to settle, and this substrate provides a stable, organic-rich, and high-moisture matrix for polychaete worms and other soft-bodied infauna to thrive (μ >1,000 m^{-2}). These worms are generally 2-3 × the body size of amphipods, and as a result, prey biomass density is among the highest in these flats. These organisms may also contribute to the formation and maintenance of fine substrates through the production of fecal pellets (Hayes and Michel 2008). Silt/clay content is high compared to other habitats (4.3 ± 0.3 %). Elevation is generally moderate (1.1 ± 0.03 m MLLW), providing foraging accessibility over 50% of the tide cycle. These features are often situated near roosting habitats and other foraging habitats which both provide additional value. Signs of benthic infauna (castings, burrows, casings, p. 6) are often visible, along with other foraging indicators (droppings and footprints, inset at bottom). Vegetation, typically *Spartina alterniflora*, is usually absent or very sparse (p. 8). Available biomass is high, resulting from a combination of dense polychaete community and large individual organism size *(e.g., Laeonereis culveri* μ 0.79 mg AFDW). Sheltered flats are somewhat rare at the landscape scale, but are predictable in their locations, usually occurring on the southern side of inlets or the protected side of sand spits and inlet shoals.

Sheltered flats										
Waves									■	**Calm**
Sandy								■		**Muddy**
Low in tide frame						■				**High in tide frame**
Amphipods									■	**Worms**
Low biomass									■	**High biomass**
Low bird activity									■	**High bird activity**
Common						■				**Rare**



Sheltered flats are rare at the landscape scale, but occur in predictable places, such as on the protected side of sand spits (a). These features can vary in appearance and substrate, including light rippling of fine sand with algae (b, Deveaux Bank) or mucky (c, Captain Sam's Inlet). Typically these are dominated by large polychaete worms (b, inset) and signs of bird foraging are abundant (c, inset)

Depressions: isolated and semi-isolated

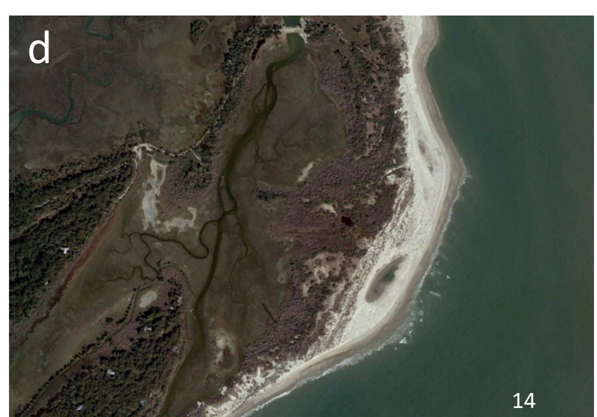
These features, also referred to as cat's eye ponds, inter-ridge ponds, swale ponds (Otvos 2000), or lagoonal depressions, form when an intertidal habitat is enclosed on three or more sides by dry or mostly dry sand. The formation of these small features (100-400 m across) can occur during sand spit formation and progradation or as a result of the inlet bar welding process (Otvos 2000, Hayes and Michel 2008). In this document two types are distinguished. Semi-isolated depressions are still open to tidal exchange and isolated depressions are fully isolated from surface tidal exchange except during extreme water level events. The result is an accumulation of fine sediments and denser, worm-dominated prey community. In cases where the enclosure occurs quickly, the substrate can be coarser sand. While a similar prey resource occurs on sheltered mudflats, the tidal isolation of these features can provide foraging access nearly 95% of the time for isolated depressions (57% for semi-isolated), as compared to roughly 50% of the time for sheltered flats. Depressions are often located away from humans and pets, further adding to their high value. However, these features are also very rare at the landscape scale, occurring in only two or three places along the SC coast at any given time.

Isolated and semi-isolated depressions											***Shading: isolated=black, semi-isolated=gray***
Waves										■	**Calm**
Sandy				■	■	■	░	░			**Muddy**
Low in tide frame							░	░		■	**High in tide frame**
Amphipods								░	■	■	**Worms**
Low biomass						░	░			■	**High biomass**
Low bird activity								░	░	■	**High bird activity**
Common								░	░	■	**Rare**

Semi-isolated depressions often form in series on recurved sand spits as seen at Captain Sam's spit in 2015 before it was severed during an inlet relocation project (left). Both types of depressions can contain polychaete densities in excess of 2,000 m^{-2} (right).

Depressions, continued

Isolated depressions are rare and can form when enclosed by a sand spit (Hilton Head Island, a) or via inlet bar welding (Captain Sam's Inlet, b). Depending on how quickly they are enclosed, the substrate can range from muck to sand. Evidence of bird foraging is often abundant (c). Dewees Island may also support depressions periodically as seen here, circa 2018 (d).



Habitat comparison chart

Beach flats: ocean-facing

Dark shading indicates the most common characteristic of a given habitat

Waves	■										Calm
Sandy			■								Muddy
Low in tide frame		■									High in tide frame
Amphipods		■									Worms
Low biomass						■					High biomass
Low bird activity				■							High bird activity
Common	■										Rare

Runnels: inlet- and ocean-facing

Shading: inlet=black, ocean=gray

Waves				▒	■						Calm
Sandy		▒	■								Muddy
Low in tide frame							▒	■			High in tide frame
Amphipods	■										Worms
Low biomass						▒		■			High biomass
Low bird activity					▒	■	■				High bird activity
Common					▒	■					Rare

Beach flats: inlet-facing

Waves			■	■							Calm
Sandy			■	■	■						Muddy
Low in tide frame		■									High in tide frame
Amphipods		■	■	■							Worms
Low biomass							■				High biomass
Low bird activity						■					High bird activity
Common		■									Rare

Sheltered flats

Waves									■		Calm
Sandy								■			Muddy
Low in tide frame						■					High in tide frame
Amphipods									■		Worms
Low biomass									■		High biomass
Low bird activity									■		High bird activity
Common						■					Rare

Isolated and semi-isolated depressions

Shading: isolated=black, semi-isolated=gray

Waves										■	Calm
Sandy				■	■	■	▒	▒			Muddy
Low in tide frame							▒	▒		■	High in tide frame
Amphipods								▒	■	■	Worms
Low biomass						▒	▒			■	High biomass
Low bird activity								▒	▒	■	High bird activity
Common								▒	▒	■	Rare

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