

Recovery of Infaunal Crustacean Colonies Following a Period of Rapid Sedimentation and Defaunation: A Neoichnological Examination Following Beach Rejuvenation on the South Side of Packery Channel, North Padre Island, Texas

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ABSTRACT

Infaunal and epifaunal burrowing organisms commonly experience environmental stress as a consequence of rapid increases in sedimentation rate. If the increase in sedimentation rate is gradual, organisms can respond by adjusting their burrow geometry to accommodate the new location of the sediment-water interface. If sedimentation rate is very rapid, environmental stress may result in organisms experiencing major colonial disruption or even total defaunation. In the ancient rock record, it is documented that the burrows of infaunal crustaceans (*Ophiomorpha* and *Thalassinoides*) are present in both fair-weather and storm deposits, although there is little information about the rate of re-colonization following a major storm event or a rapid increase in sedimentation rate, such as that produced by a wave-dominated delta system during the rapid deposition of a stream mouth bar onto underlying shoreface sands.

Recent nourishment and rejuvenation of a 3800 ft (1.2 km) section of beach, facilitated by re-deposition of 110,000 yd³ (84,100 m³) of sand dredged during re-opening of littorally-closed Packery Channel, provides an excellent opportunity to examine response of infaunal burrowing crustaceans to a sudden increase in vertical sediment rate to 0.6-5.0 ft/year (0.2-1.5 meters/year) and/or rapid beach progradation. Sand re-deposition and subsequent storm-induced littoral drift resulted in over 330 ft (100 m) of beach progradation between December 2003 and August 2005.

Recent investigations of population densities of ghost shrimp *Callichirus islagrande* on the beach south of Packery Channel South Jetty provides quantitative data on the re-colonization rate of these infaunal burrowing crustaceans. Since August 2005, *Callichirus islagrande* have almost returned to normal North Padre Island colonial densities, at an average lateral, landward re-colonization rate of 33.8 ft/month (10.3 m/month).

INTRODUCTION

Ichnofossils (i.e., trace fossils) are widely used in making sedimentological and paleoenvironmental models for ancient shoreline depositional systems. Burrows and traces, when grouped into ichnofacies, based on the apparent adaptation of groups of trace-making organisms to similar sets of environmental conditions, have been shown to be reasonably good indicators of environmental factors such as water bathymetry, turbidity, energy, and salinity and of substrate consistency which are key to making correct and realistic paleoenvironmental and depositional interpretations (Pemberton et al., 1992a). Neoichnology, defined as the study of modern burrowing and trace-making organisms, has been invoked to quantify and calibrate ichnofacies as environmental and ecological indicators, where the depositional environments are known. Most neoichnological studies have been conducted along macro-tidal and meso-tidal shorelines

because of the ease of the examination of depositional surfaces of sand and mud tidal flats that are frequently exposed by large diurnal tides. This study is a part of a major neoichnological study of the micro-tidal Gulf Coast of Texas in an attempt to calibrate ichnofacies in micro-tidal shoreline systems (Garrison et al., 2007).

CATASTROPIC SEDIMENTOLOGICAL EVENTS

Catastrophic events are common in the sedimentary record and reflect the episodic nature of sediment deposition. Catastrophic sedimentological events can be recorded as major erosive events or sudden increases in local sedimentation. These events can be grouped into storm events (e.g., representing the destruction or enhancement of shoreline environments due to major storms and hurricanes) (Pemberton et al., 1992b) (Fig. 1A) and riverine flood events (e.g., representing the sudden introduction of sediment into the littoral system by major floods) (Rodriguez et al., 2000) (Fig. 1B).

The response of trace-making organisms to these catastrophic events is a function of the intensity and duration of the events and the general biological and population characteristics of the organisms (Pemberton et al., 1992b). Burrowing and trace-making organisms can be grouped into two categories: K-selected species (equilibrium communities) and r-selected species (opportunistic species) (Boesch and Rosenberg, 1981). Opportunistic r-selected species lack an equilibrium population size, have the ability to increase population density rapidly, and have high dispersal ability (Grassle and Grassle, 1974), all of which result in broad environmental tolerances and the ability to rapidly colonize open niches (Pianka, 1970). Opportunistic species tend to be tolerant of physiologically stressful environments, such as foreshore and shoreface depositional environments. Therefore, they are common burrowers in beach and shoreface environments which are stressed due to high hydrodynamic energy and are also subject to catastrophic erosion and depositional events.

Catastrophic events commonly lead to defaunation or possibly the establishment of temporary orphan communities of r-selected, opportunistic species. Data on the ability of these species to re-colonize following colonial disruption or defaunation is abundant for infaunal and epifaunal polychaetes (Vossler and Pemberton, 1988), but rare for crustacean taxa such as *Callichirus* spp., and *Corophium* spp. These crustacean taxa are responsible for producing key ichnofossils found within ancient foreshore and shoreface successions.

The purpose of this study is to document and quantify the re-colonization rate of the ghost shrimp *Callichirus islagrande* following catastrophic defaunation due to an anthropologically-induced increase in vertical sedimentation rate and subsequent rapid beach progradation.

ANTHROPOLOGICALLY-INDUCED SEDIMENTATION AT PACKERY CHANNEL

Although rapid catastrophic sedimentation and erosion events are common geologic occurrences that have been well-documented, in the ancient rock record, the timing of these events is generally unpredictable. Therefore, an analysis of the response of modern, r-selected species to these geological events is all but impossible, except during a few rare opportunities. Anthropologically-induced sedimentation events facilitated by civil engineering construction

projects and/or beach nourishment projects, provide an alternative opportunity to examine the behavior of opportunistic burrowing and trace-making species as they respond to colonial disruption and defaunation.

Packery Channel Study Area

Packery Channel was the last stable position of a tidal channel in a relict washover channel/tidal inlet complex located between Padre and Mustang Islands (Fig. 2). Enlargement of Aransas Pass in 1912 for navigation purposes reduced the amount of tidal discharge through Packery Channel, ultimately resulting in its closure, by littoral drift of sediment along the beachface of Mustang and North Padre Islands. Except for temporary opening of the channel by hurricanes, it remained closed after 1930 (Price, 1952).

In 1967, a seawall was constructed to protect a small group of condominiums and motels on the Gulf shoreline and a small residential community located on the margins of the tidal channel (Fig. 3). The 11.5 ft (3.5 m) high seawall was originally located on the backbeach in front of the foredune ridge, between two periodic hurricane channels in the abandoned inlet (Suter, 1987). Historical monitoring of the shoreline before the seawall was built indicated that the beach was relatively stable (Morton and Pieper, 1977). Following seawall construction, there has been a shift to minor beach erosion, and a steepening and narrowing of the beach profile (Suter, 1989).

In September 2003, the U.S. Army Corp of Engineers initiated a project to dredge-open the littorally-closed Packery Channel to a depth of 11 ft (3.4 m) and a width of 300 ft (91 m) for boat access between the Gulf of Mexico and Corpus Christi Bay. Beginning in December 2003, 110,000 yd³ [Flag: superscript 3] (84,100 m³) [Flag: superscript 3] of sand was dredged from the channel and pumped onto the eroded beach from the south side of the channel to the south end of the seawall to nourish and rejuvenate the beach. In July 2005, storm surge by hurricane Emily opened the channel and distributed the sand across the North Padre Island shoreface on the south side of Packery Channel. In an attempt to prevent closure of the channel by subsequent littoral drift of sediments into the channel's mouth, two 1400 ft (427 m) long rock jetties were constructed.

Sedimentation, Beach Progradation, and Beach and Shoreface Defaunation

The redistribution of the sand onto the beach and shoreface between Packery Channel and Whitecap Beach resulted in a dominantly anthropological-induced increase in vertical sedimentation and beach progradation. The re-deposition of 110,000 yd³ (84,100 m³) of sand dredged during re-opening of Packery Channel produced a sudden artificial increase in vertical sediment rate to 0.6-5.0 ft/year (0.2-1.5 meters/year) on the beach and upper shoreface and resulted in rapid beach progradation. Sand re-deposition and subsequent storm-induced littoral drift resulted in over 330 ft (100 m) of beach progradation between December 2003 and September 2005 (Fig. 3) and the blanketing of the upper shoreface to a depth up to 4.3-5.0 ft (1.3-1.5 m) in sand. This sediment blanket extended out from 625-1120 ft (190-340 m) from the 2003 high tide line (Fig. 4). Beyond the south end of the seawall at Whitecap Beach, the beach profiles do not indicate significant sand accumulations. This increase in vertical sedimentation

rate and subsequent beach progradation resulted in the major defaunation of the *Callichirus islagrande* population out 625-1120 ft (190-340 m) in the upper shoreface.

RESPONSE OF INFAUNAL CRUSTACEANS TO CATASTROPHIC SEDIMENTATION

A quantitative population survey was conducted at Malaquite Beach on the Padre Island National Seashore to document the systematics of normal (pre-catastrophic) *Callichirus islagrande* [Flag: italicize *Callichirus islagrande*] populations on North Padre Island. A series of quantitative population surveys were also collected at four transects (Fig. 3A) along a 3800 ft (1.2 km) section of beach south of Packery Channel to monitor and document the recovery rate of *Callichirus* populations following the anthropologically-induced increase in vertical sedimentation rate and subsequent beach progradation.

BIOLOGY AND ECOLOGY OF *Callichirus islagrande*

Callichirus islagrande [Flag: italicize *Callichirus islagrande*] is a common inhabitant of beach and barrier island shoreface of Mustang and North Padre Islands. *Callichirus* can tolerate salinities that range from 20 parts per thousand (ppt) up to 40 ppt (Garrison et al., 2007). The domicinal burrow of *Callichirus* is a complex lined burrow that may extend as much as 3 ft (1 m) down into the sandy sediment substrate. The upper part of the burrow is a small mucus-lined vertical tube that commonly only about 0.2 in (5 mm) in diameter and may extend down 4-6 in (10-15 cm) (Fig. 5). This small opening connects at depth to a wider 0.6-10 in (15-25 mm) lined burrow that may extend down to depths of 3 ft (1m) or more. These vertical burrow shafts may connect to a series of horizontal burrows at depth (Bromley, 1996). The small vertical opening is a protective adaptation, since the *Callichirus* normally never leaves the burrow. Although *Callichirus* is commonly found in colonies, communication with neighboring burrows is avoided.

Callichirus islagrande is a suspension feeder, although some species of *Callichirus* and *Callianassa* are deposit feeders. *Callichirus* uses its pleopods to set up a flow of water into the burrow. It then filters out food and fine sediment from the inflowing water. After 15-30 minutes, the flow is reversed and mud-rich fecal pellets are expelled out of the burrow onto the surface (Fig. 5). *Callichirus* also uses captured mud and fine sediment mixed with mucus to form round pellets that are applied to the walls of the lower part of the burrow system to stabilize the burrow. The inside of the burrow is smoothed flat, but hemispherical (nodose) projections form the outside of the lining layer (Bromley, 1996).

The burrow of *Callichirus islagrande* is preserved in the rock record as the vertical and horizontal *Ophiomorpha nodosa* and *Thalassinoides* ichnofossils. Colonies of *Callichirus* and *Callianassa* may destroy as much as 70%-80% of the sedimentary structures (Bromley, 1996).

Callichirus islagrande burrows have been identified within colonies in foreshore, upper shoreface, and middle shoreface facies along the beachface of North Padre Island. *Callichirus* live in colonies (Fig. 8), therefore their distribution is not uniform over large distances even between depositional facies or within a particular depositional facies.

RECOVERY FROM INCREASED SEDIMENTATION AND/OR DEFAUNATION

In response to small increases in sedimentation, *Callichirus islagrande* will quickly expand their burrow opening upward to the sediment water interface and then proceed to stabilize the newly expanded domichnia by reinforcing the newly created walls with pellets. More rapid vertical sedimentation and burial under a thick sand blanket will close burrows, prevent water circulation, and subsequently result in mortality and defaunation.

Figure 6A shows a population density profile across the landward side of a *Callichirus islagrande* colony at Malaquite Beach. Data for this profile were collected during a -0.5 ft (-0.15 m) low spring tide on February 18, 2007 when the uppermost part of the upper shoreface was exposed in very shallow water. This profile reflects the stable conditions existing during slow normal littoral sedimentation. The population density drops off gradually from upper shoreface to foreshore reflecting the stressed conditions within the intertidal zone and the foreshore swash zone.

Figure 6B shows a similar population density profile about 164 ft (50 m) south of the South Packery Channel Jetty. Population profiles were also collected at positions along the seawall at south of the seawall at Whitecap Beach (Fig. 3). Data for these profiles were collected during a -0.7 ft (-0.21 m) low spring tide on February 17, 2007.

A comparison of most landward position of the *Callichirus islagrande* colony exhibited by the Malaquite Beach population profile to that exhibited by the profiles taken along the seawall indicates that the colonies south of Packery Channel have not fully recovered from the anthropologically-induced defaunation. The most landward extent of the colony at Whitecap Beach is similar to that at Malaquite Beach indicating that the defaunation did not extend beyond the south end of the seawall, as predicted from an examination of the beach survey profiles at Whitecap Beach.

The most landward positions of the *Callichirus islagrande* colonies south of Packery Channel were monitored over a five month period. No burrows were observed within the foreshore until late January 2007. Figure 7A shows the landward re-colonization south of Packery Channel between February 17, 2007 and March 16, 2007. These data indicate that the mean short term recovery rate of the opportunistic *Callichirus* is 44.9 ft/month (13.7 m/month). Assuming that the most seaward extent of the sand blanket in 2005 represents the most landward position of surviving colonies following the beach rejuvenation, we can estimate the mean long term recovery rate. Figure 7B shows the colonial expansion since July 26, 2005. The mean long term recovery rate is calculated to be 33.8 ft/month (10.3 m/month), consistent with the calculations made using the February 17, 2007 and March 16, 2007 data. No colonial expansion was noted in the foreshore prior to January 2007 because the colony was still underwater and unobservable further seaward in the surf zone of the upper shoreface.

IMPLICATIONS FOR THE ICHNOLOGY OF SHORELINE SEDIMENTS

Catastrophic events are common in the sedimentary record and reflect the episodic nature of sediment deposition. These catastrophic sedimentological events can be recorded in the

sedimentary column as major erosive events or as sudden increases in sedimentation. These events can be grouped into two categories: storm events (Pemberton et al., 1992b) (Fig. 1A) and riverine flood events (Rodriguez et al., 2000) (Fig. 1B).

Pemberton et al. (1992b) have developed a methodology for the use of ichnofossils (preserved burrows and traces) in recognizing tempestites (i.e., storm events). Their approach is based on the recognition of (1) the initial fair-weather faunal suite, (2) the erosion associated with the initiation of the storm event, (3) the escape structures associated with the fauna responding to the increase in sediment, and (4) the re-establishment of a fair-weather community following the storm event. They used examples from the *Cardium* Formation of the Western Interior Basin of Canada to illustrate this concept. They presented data from a variety of studies that provided information of recovery rates of various opportunistic, r-selected taxa. Little data was presented that addressed the response of thalassinidean crustaceans to such tempestite events. Since thalassinidean crustaceans are key ichnofossils in sediments deposited in high energy marine shoreface environments, this study is timely and provides some useful information.

It is common to address the role of riverine versus wave processes in the development and recognition of shoreline systems. This approach commonly involves the use of key high energy marine ichnofossils to delineate the influence of marine processes from those that are dominantly produced by riverine processes. Our data suggest that this approach is overly simplistic. For example, in the Brazos River flood of 1992, a large mouth bar was deposited and as flood waters receded, the bar became emergent (Rodriguez et al., 2000). This 1000 ft (300 m) wide, 1.6 mi (2.5 km) long mouth bar sand was subsequently translated south of the river mouth by littoral processes and welded onto the beach on the south side of the delta. This massive sand body was initially devoid of thalassinidean crustaceans. This would be expected from our knowledge of the riverine origin of the sand body. But, our data suggests that within less than 3 years, following the return of the waters to inter-flood stages, near marine salinities and the dispersal of fine suspended sediment further offshore, the newly formed beach ridge would be colonized by *Callichirus islagrande* and be recognized as a normal marine beach and shoreface facies succession, with all evidence of a freshwater origin lost. Without historic data, this conclusion cannot be quantitatively verified, but our examination of this welded beach ridge in March 2006 indicated that a normal *Callichirus* colony was in fact present. We also noted that during inter-flood periods the waters at the Brazos River mouth and the waters surrounding the emergent mouth bar/beach ridge quickly return to near marine salinities. This rapid return to near marine salinities would further stimulate a rapid colonial recovery. In addition, we have observed that the *Callichirus* also expand into sandy niches along the river banks, several hundred meters up river from the river mouth.

These observations and the observations of Garrison et al. (2007) suggest that *Callichirus islagrande* is very opportunistic and will rapidly expand into all available sandy niches that are available in non-turbid, moderate to high energy waters of marine or near marine salinities. This implies that the use of the ichnofossils *Ophiomorpha* and *Thalassinoides* as discriminators of marine versus riverine environments, without consideration of colonial expansion rates and rapid changes in salinities, can be inconclusive and somewhat problematic.

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Figure 1. (A) Oblique aerial photograph of a storm produced tidal inlet located 8 mi (13 km) southeast of the Brazos River mouth. The inlet and tidal delta developed within the past decade. (B) 1996 U.S.G.S. aerial photograph of the Brazos River delta near Freeport, Texas.

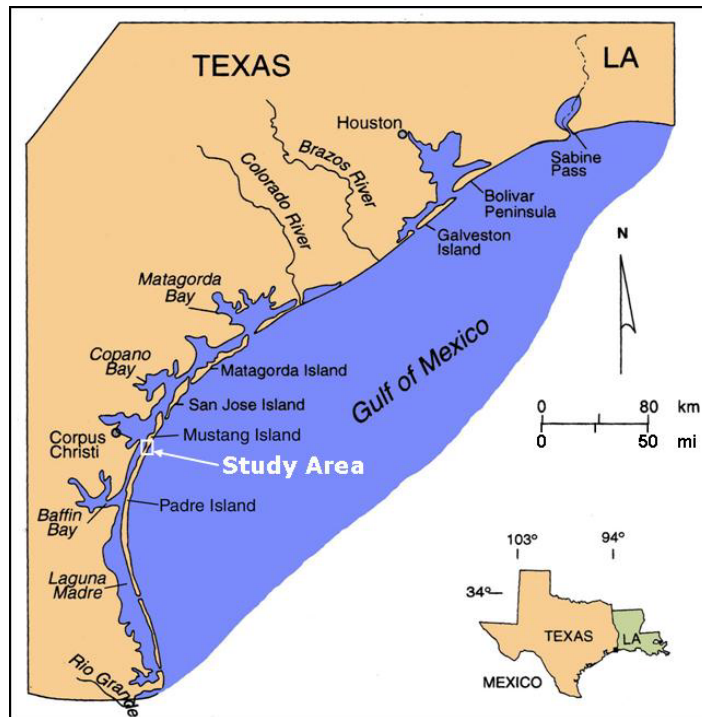


Figure 2. Map showing the Gulf Coast of Texas and the location of the study area (after Morton et al. (2000) with permission of SEPM).



Figure 3. (A) 1996 U.S.G.S. aerial photograph of the Packery Channel area at the north end of Padre Island showing data collection locations. Aerial photographs of the Packery Channel area taken in (B) September 2003 and (C) August 2005. 2003 and 2005 photographs courtesy of the Conrad Blucher Institute for Surveying and Science, Texas A&M University – Corpus Christi.

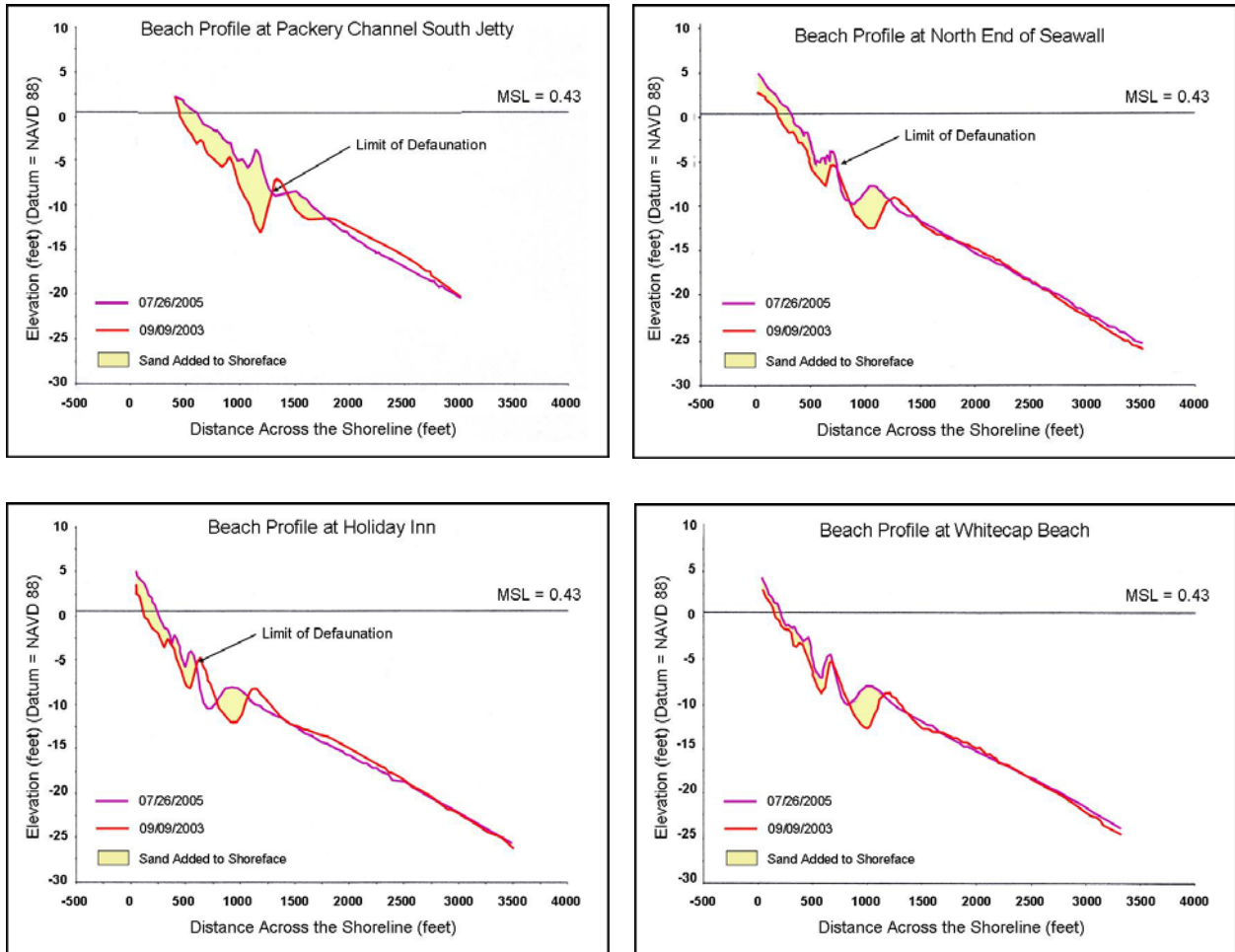


Figure 4. Beach profile data collected at each observation site. Data from Williams et al. (2005).



Figure 5. Photograph of (A) *Callichirus islagrande* (inset) and its burrow opening and (B) a *Callichirus islagrande* colony exposed at low spring tide at Malaquite Beach.

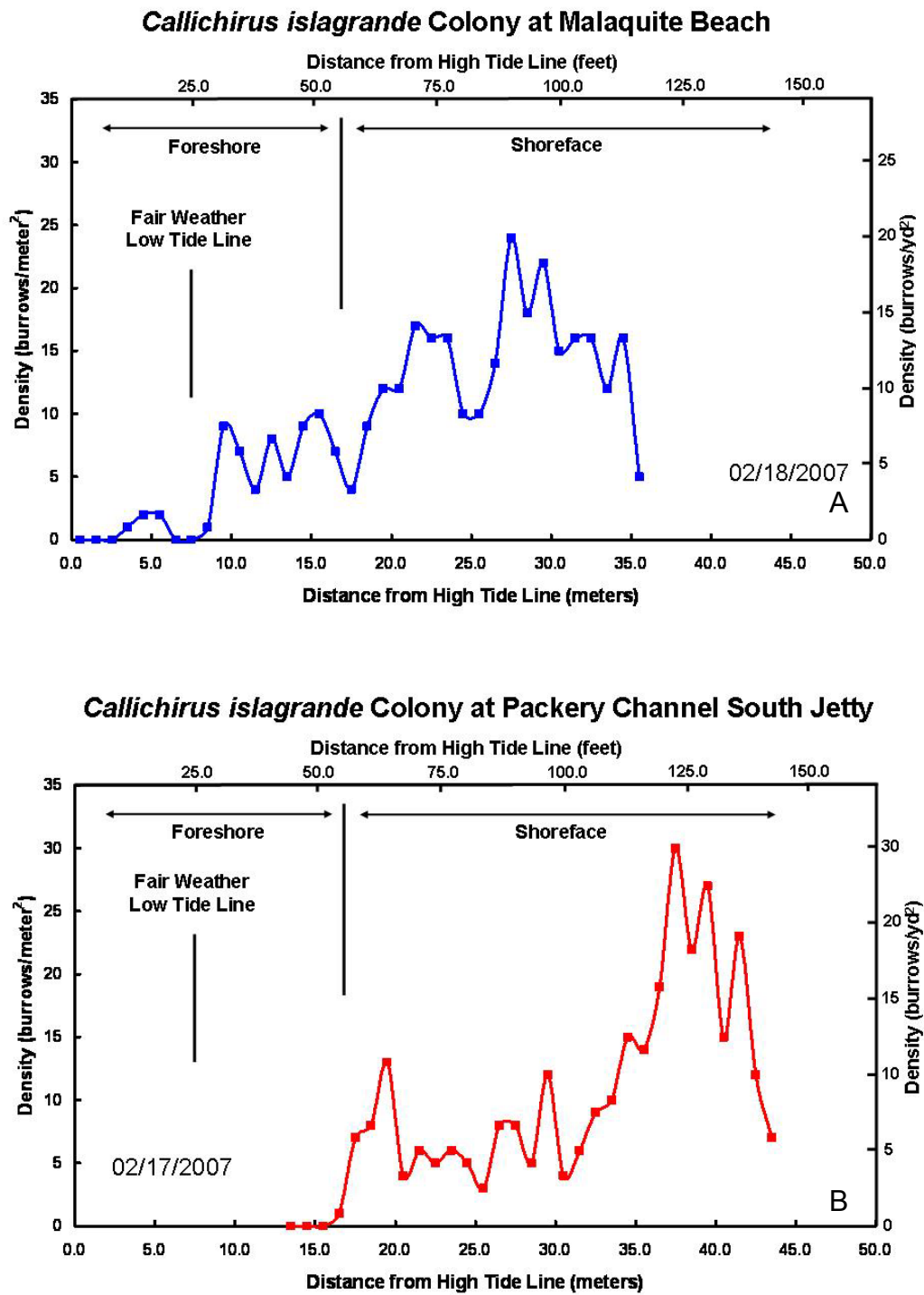


Figure 6. Population density profiles of *Callichirus islagrande* at (A) Malaquite Beach and at (B) the South Packery Channel Jetty.

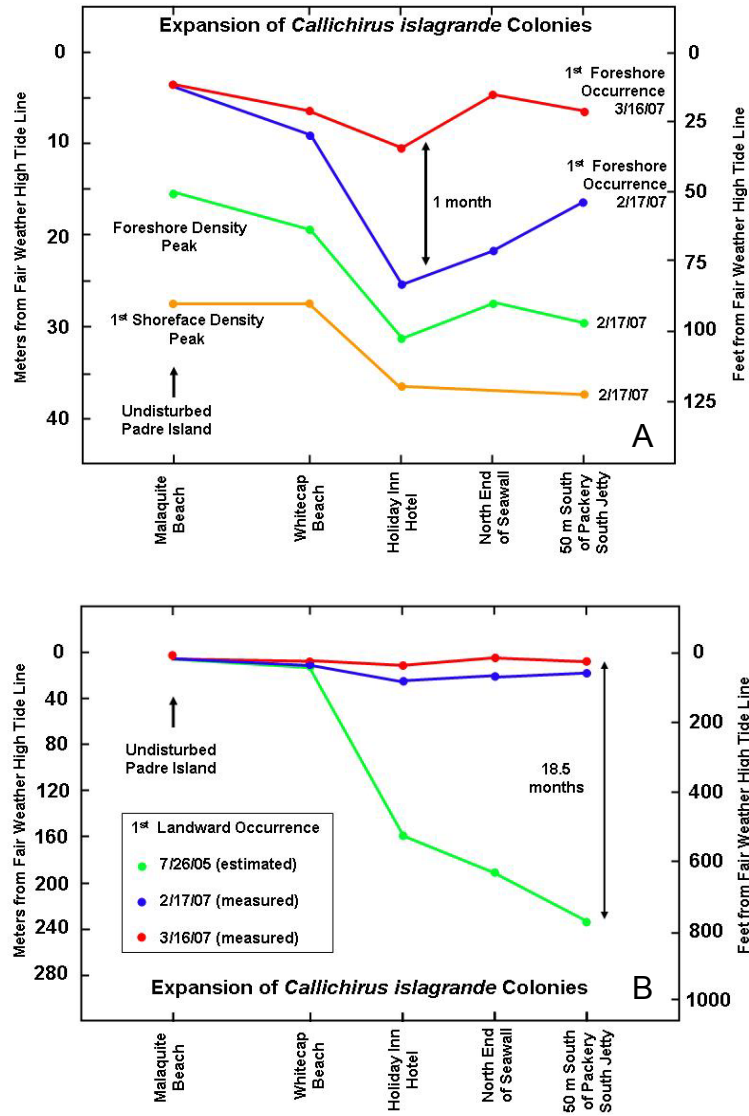


Figure 7. Profiles showing (A) the short term and (B) the long term landward expansion of *Callichirus islagrande* south of Packery Channel following defaunation.