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NOTE

JUVENILE BLUE CRAB ABUNDANCES IN NATURAL AND MAN-MADE TIDAL CHANNELS IN MANGROVE HABITAT, TAMPA BAY, FLORIDA (USA)

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The blue crab (*Callinectes sapidus* M. J. Rathbun, 1896) is an ecologically and commercially important species common in the Gulf of Mexico and Western Atlantic Ocean (Virnstein, 1977; Hines et al., 1990; Guillory et al., 1998). The life cycle of the blue crab is considered to be classically estuarine-dependent with females mating within the estuary then migrating offshore to spawn. Larvae are transported back into estuarine habitats where they settle and grow to adult sizes (Tagatz, 1968).

Studies of habitat utilization by juvenile blue crabs have focused largely on seagrass, saltmarsh, and unvegetated habitats. Previous studies indicate that seagrass and saltmarsh habitats are important to juvenile blue crabs: researchers report higher juvenile densities, decreased predation, and/or faster growth rates compared to unvegetated habitats (Orth and van Montfrans, 1987, 2002; Thomas et al., 1990; Williams et al., 1990; Perkins-Visser et al., 1996; Rozas and Minello, 1998; Rozas and Zimmerman, 2000). While the use of saltmarsh and seagrass by juvenile blue crabs is relatively well understood, knowledge of mangrove wetlands as habitat for blue crabs is limited. In Rookery Bay, Florida, blue crab densities were lowest in intertidal mangrove habitat, and higher in seagrass and open water (Sheridan, 1992). However, a study comparing mangrove and saltmarsh habitats in Caminada Bay, Louisiana found that blue crabs were more closely associated with mangrove habitat and suggested that this relationship was due to the greater structural complexity offered by mangroves (Caudill, 2005). However, juvenile densities were not reported in these two studies.

Coastal wetlands, including mangrove habitats, are being increasingly altered or destroyed by human development (Dahl, 1990; Valiela et al., 2001). An area of increasing interest to scientists and habitat managers is the ecological equivalency of altered and restored habitats relative to natural habitats. Contrasting results on the functioning of non-natural wetlands have been presented from studies of blue crab habitat use (Minello, 2000; Peterson et al., 2000; Jivoff and Able, 2003), suggesting that the effects of habitat alteration (both the type and degree) on wetland communities, and specifically for blue crabs, have yet to be fully explained.

Within Tampa Bay, Florida, common forms of wetland alteration have been ditching for mosquito control and stormwater drainage. Mosquito-control ditches were constructed in the 1960s and 1970s to inundate poorly flushed coastal wetlands and allow access for fishes that consume mosquito larvae. Stormwater-drainage ditches were constructed to convey rainwater runoff from residential areas to Tampa Bay and thereby prevent urban flooding. Direct comparison of fauna in altered vs natural wetlands provides insight into how human activities affect mangrove wetland function and is particularly important for assessing restoration need and/or efficacy.

The objective of this study was to determine if juvenile blue crab abundance differed between naturally formed tidal creeks and man-made ditches in mangrove wetlands.

To address this objective, we first estimated the natural spatial variability of crab abundance among three naturally formed tidal creeks. This allowed establishment of a baseline by which comparisons could be made with man-made ditches. Second, we compared crab abundance between tidal creeks and man-made mosquito-control ditches within two of the wetland regions. Third, in addition to alterations caused by mosquito ditching, one of our sample regions (i.e., Mobbly Bayou) had been altered for stormwater drainage, allowing us to compare tidal creeks with two types of man-made habitat within a wetland. The null hypothesis for each objective was one of no difference in juvenile blue crab abundance between sample regions and/or habitat type (i.e., naturally formed and man-made tidal channels).

Materials and Methods

Sample Regions.—Sampling was conducted in State and County preserves within three wetland regions along a north-south transect within the Tampa Bay estuary, Florida (USA) (Fig. 1). Sample sites in the naturally formed tidal creek in the Terra Ceia region (lower bay) were located closest to the mouth of the estuary. Weedon Island (mid bay) is located along the Tampa Bay shoreline near the middle of the estuary and is the location of extensive gridded mosquito ditching. Feather Sound (mid bay), approximately 8 km north of Weedon Island, contains a tidal creek that empties directly into Tampa Bay. Mobbly Bayou (upper bay) is located at the northern-most extent of Tampa Bay. The tidal creek at Mobbly Bayou runs through the center of the County preserve, while three stormwater-drainage ditches were constructed parallel to the creek at its upstream, central, and downstream reaches. Mosquito-control ditches are located in the central portion of the Mobbly Bayou wetland approximately 200 m northeast of the creek, as well as in the fringing mangroves along the shoreline of Tampa Bay. Unlike mosquito-control ditches, stormwater-drainage ditches are less common features in the wetland landscape and differ from mosquito-control ditches in their linearity and their conductance of larger water volumes. These differences are related to their intended purpose and have resulted in contrasting hydrology, channel widths, water depths, and bottom substrates (Krebs, unpubl. data).

Sample Design.—For each sample region (e.g., upper bay), random points were selected within each habitat type. Fixed sites were installed as close as possible to these randomly-generated points. Each of the 49 fixed sites was sampled twice from December 2003 to May 2004 (i.e., once each season during recruitment). To estimate the natural spatial variability of juvenile blue crab abundances in naturally formed channels, we sampled tidal creeks in the upper bay (n = 9 fixed sites), mid bay (n = 6), and lower bay (n = 6) regions. To compare crab abundance in natural and man-made habitat types, we sampled sites within mosquito-ditched wetlands. This comparison of natural and man-made habitat was limited to mosquito-control ditches in upper bay (n = 9 fixed sites) and mid bay (n = 10) regions because of the absence of mosquito-control ditches in the lower bay sample region. Finally, abundance of juvenile blue crabs was compared among sites in tidal creeks and two types of man-made habitat: mosquito-control ditches and stormwater-drainage ditches (n = 9 fixed sites) in the upper bay region.

Crabs were sampled by isolating a 9.1-m-long section of the creek or ditch using two block nets (3-mm mesh) and seining through the site using a center bag haul seine (1.2 m deep with 3-mm mesh) stretched across the channel from bank to bank. Size of block nets (4.6 m, 6.1 m, 9.1 m, 12.2 m, or 15.2 m) and seines used depended on channel width. Blue crabs were enumerated and carapace width (CW) was measured to the nearest 1-mm for the first 20 individuals from each sample.

Statistical Analysis.—For analysis, juvenile crabs were defined as those < 80 mm CW. Size frequency distributions from this study (Yeager et al., unpubl. data) and previous studies (Fitz and Wiegert, 1991; Hsueh, 1992; McClintock et al., 1993) suggest that this is a conserva-

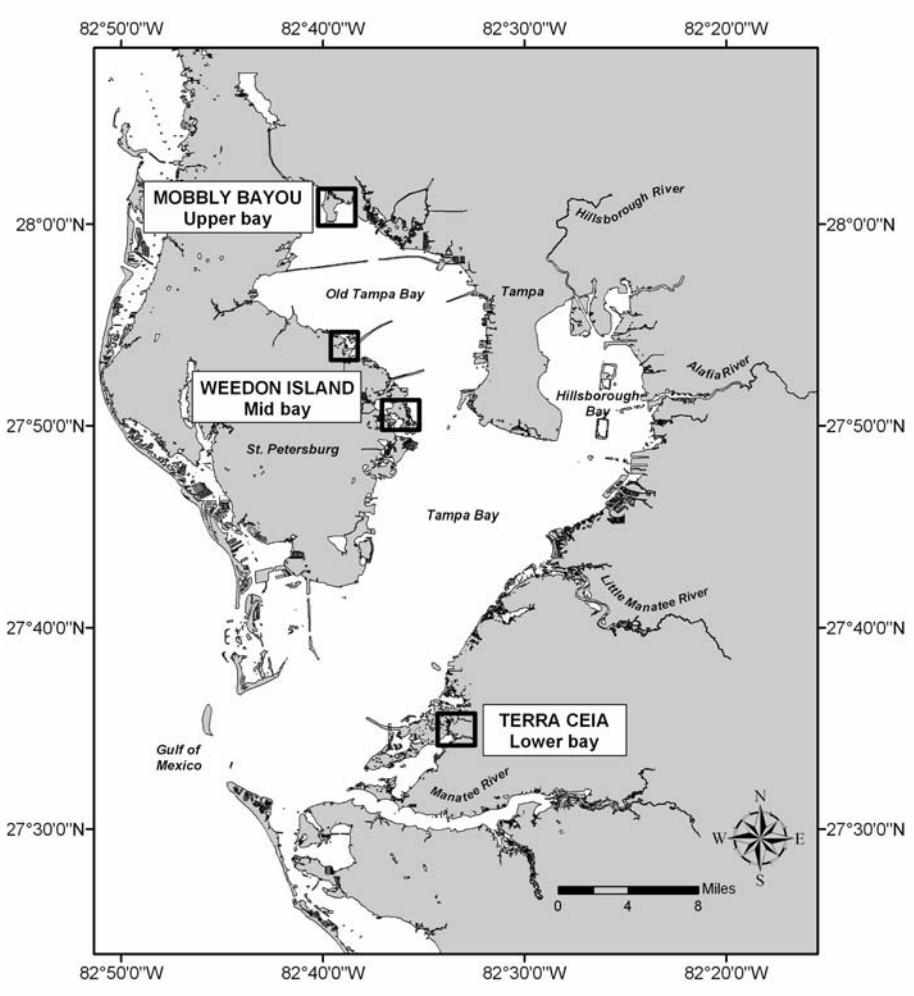

Figure 1. Location of sample sites within lower (Terra Ceia), mid (Weedon Island), and upper bay (Mobbly Bayou) regions of Tampa Bay along the west coast of Florida (USA).

tive estimate of maximum size for young-of-the-year (YOY) juveniles. For all analyses, abundance of juvenile crabs was measured as the number of crabs 100 m^{-2}. To test for a statistical difference in the abundance of juvenile blue crabs among three naturally formed tidal creeks, we used a repeated measures analysis of variance (RMANOVA) with maximum likelihood estimation. Season (i.e., winter and spring) was the repeated variable. Because samples from fixed sites were not independent of one another, spatial autocorrelation resulting from repeated sampling of fixed sites was accounted for using a covariance structure that was first order heterogeneous autoregressive whereby autocorrelation diminishes through time. We then compared the abundance of juvenile blue crabs between tidal creeks and mosquito-control ditches in the upper and mid bay regions using a similar RMANOVA to test the null hypothesis of no difference between naturally formed and man-made habitat types within both regions. Finally, we compared juvenile crab abundance among tidal creeks, mosquito-control and stormwater-drainage ditches in the upper bay region using RMANOVA as above. Tukey multiple comparison tests were used to identify the source of the difference, when present. In all cases, data were log $(x + 1)$ transformed prior to analysis. Data met the assumption of normality (Shapiro-Wilk; $P > 0.05$) with the exception of the comparison of tidal creeks and

mosquito-control ditches (w = 0.9877, P = 0.0217). However, given the sample size (n = 68 samples) and the robustness of ANOVA to departures from normality (Zar, 1999), we feel this use of a parametric test was justified. All analyses were performed using SAS version 9.1 (SAS Institute, 2003).

Results

Young blue crabs recruited to our study sites in Tampa Bay wetlands during winter and spring (December 2003–May 2004). Abundances of juvenile crabs in mangrove wetlands (natural and man-made) during the winter season (December–February) ranged from 0–222.2 crabs 100 m^{-2}. The modal size of juvenile blue crabs during this time was 10–20 mm CW within all three sample regions. During the spring season (March–May) abundances ranged from 0–225.4 crabs 100 m^{-2}. Modal size remained constant from winter until the end of spring at which time the modal size was observed to have increased to 30–50 mm CW. A concurrent decrease in the range of abundances to 0–34.2 crabs 100 m^{-2} during the summer (June–August) was observed with the increase in modal size.

Mean abundance of juvenile crabs differed among tidal creeks in Tampa Bay during recruitment and early post-settlement (P = 0.028; Fig. 2), but only because of a significantly lower density of juvenile crabs in the mid bay during late spring. The greatest abundance was observed in the lower bay creek and was approximately three times that of the mid bay creek during early post-settlement (P = 0.026; Fig. 2). However, mean abundance in the upper bay creek did not differ from that of creeks in the mid or lower bay (P = 0.608 and P = 0.101, respectively).

Regionally, abundance of juvenile crabs was significantly greater at the upper bay wetland than the mid bay wetland (P = 0.0004), probably the result of high abundances in mosquito-control ditches in the upper bay. Juvenile blue crabs were significantly more abundant in mosquito-control ditches than in creeks, in only the upper bay region (P = 0.010; Fig. 2). There was no difference in blue crab abundance between the tidal creek and mosquito-control ditches at the mid bay wetland (P = 0.782).

Mean abundance of juvenile blue crabs differed significantly among the natural and altered habitats in the upper bay wetland (P < 0.0001). Juvenile crab abundances were greatest in the mosquito-control ditches; moderate in the tidal creek, and lowest abundances in stormwater-drainage ditches (P < 0.0001–0.002; Fig. 2).

Discussion

Abundance of juvenile blue crabs differed among natural and man-made tidal channels though not consistently at each sampled wetland, suggesting that spatial location in the estuary may be equally as important in shaping habitat use patterns as habitat type (i.e., natural vs man-made). Mosquito-control ditches have, in many cases, been shown to have a detrimental effect on wetland-associated fauna (Harrington and Harrington, 1961; Gilmore et al., 1982; Brockmeyer et al., 1997), and as a result, are frequently viewed as inferior habitat for organisms of fishery importance. Yet the highest densities of juvenile blue crabs in three types of tidal channels at 49 sites in three Tampa Bay wetlands occurred in mosquito-control ditches in the upper bay. All mosquito-control ditches sampled at both mid and upper bay wetlands were open to tidal flushing and had consolidated substrates that allowed unimpeded seine

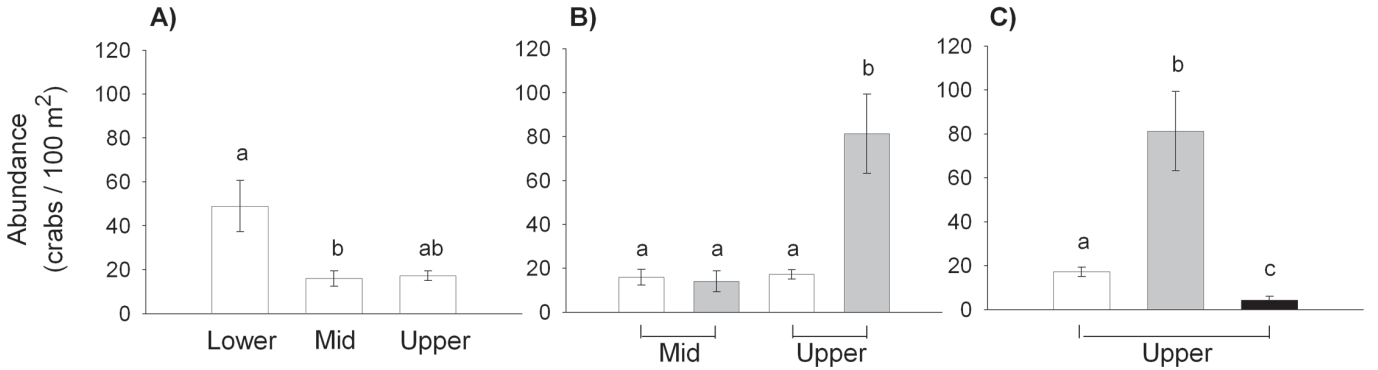

Figure 2. Mean ± SE abundance of juvenile blue crabs (< 80 mm CW) in tidal creeks (white bar), mosquito-control ditches (grey bar), and stormwater-drainage ditches (black bar) in mangrove wetlands, Tampa Bay, FL. Results of the repeated measures ANOVAs comparing (A) creeks in the lower, mid, and upper bay, (B) creeks and mosquito-control ditches in the mid and upper bay, and (C) creeks, mosquito-control ditches, and stormwater ditches in the upper bay are indicated by the letters above each bar. Bars with the same letter are not significantly different at $P < 0.05$.

sampling. There are, however, mosquito-control ditches in Tampa Bay where neither of these conditions is true and mosquito-control ditches sampled during this study may not be representative of the range of such ditches around Tampa Bay. During the time since their construction, ditches that received minimal tidal influence have accumulated sediment and were colonized by mangroves. Haul seining constraints limited sampling in ditches that possessed deep mud or dense mangrove structure (i.e., prop roots, pneumatophores). Our results clearly can not be extended to these mosquito-control ditches. Nonetheless, we found that juvenile blue crab abundances in tidally flushed mosquito-control ditches with relatively firm substrates did not differ from that of naturally formed tidal creeks in one of two bay sample regions.

The fact that the abundance of juvenile blue crabs in mosquito-control ditches differed between the mid and upper bay wetlands is cause for further consideration. The widths (mid bay = 4.5 ± 0.9 m; upper bay = 5.2 ± 0.5 m) and water depths (mid bay = 0.44 ± 0.02 m; upper bay = 0.35 ± 0.02 m) of mosquito-control ditches in these two wetlands were similar. However, at a landscape scale, the wetlands are likely positioned differently with regard to blue crab recruits transported up-estuary in bay waters, assuming passive transport of larvae (McConaugha, 1988). Circulation at the mouth of the bay is such that the lower bay creek would presumably receive a greater supply of larvae as they enter the bay from the Gulf of Mexico. The net circulation in Old Tampa Bay (i.e., upper bay in our study) is north along the eastern shoreline, and south along the western shoreline to the mid bay region (Weisberg and Zheng, 2006). This pattern is consistent with more juveniles at the lower bay than the upper bay wetland and mid bay wetland on the western shore of Old Tampa Bay, based on order of arrival of bay waters. Of the 1715 juvenile crabs collected in this study, 279 could be considered early juveniles (J3–J5, sensu Pile et al., 1996). Most of the early juveniles were found in the lower bay region (57.3%) followed by upper bay region (29.0%), further suggesting that bay circulation and transport of crab larvae may play an important role in determining patterns of habitat use. In contrast, Buchanan and Stoner (1988) found the highest proportion of small crabs at the head of the Laguna Joyuda estuary, farthest from the inlet indicating transport of juvenile crabs towards the uppermost reaches of the estuary.

A similar argument can be made at a smaller scale regarding the orientation of mosquito-control ditches in a given wetland. At the wetland in the upper bay, six of nine sampled mosquito-control ditches are located directly along the bay perimeter and all receive consistent tidal flushing (Krebs, unpubl. data). In contrast, most mosquito-control ditches at sample sites in the mid bay are located behind a series of overwash mangrove islands and receive less direct tidal input. Only three of ten mosquito-control ditches at the mid bay wetland are directly open to tidal input; the others receive tidal waters via intermediate mosquito-control ditches. Patterns of early juvenile habitat are consistent with the hypothesis that spatial configuration of habitats within a wetland may affect access to recruits. In the upper bay region, mosquito-control ditches received more early juveniles than both other habitats (76 of 82 total early juveniles at upper bay). In contrast, only five of the 27 observed early juveniles in the mid bay region occurred in mosquito-control ditches. Differences in the abundance of juvenile blue crabs in the same habitat type (i.e., mosquito-control ditches) at different spatial locations suggest that location relative to estuarine circulation must be considered as a factor affecting larval dispersal and consequently patterns of habitat use.

Abundance of recruits among habitats can also be influenced by prey availability (Seitz et al., 2005) and mortality from predation (Etherington et al., 2003). Seitz et al. (2005) suggested that unvegetated subtidal habitats adjacent to salt marshes may rival seagrasses as habitat for juvenile blue crabs because of higher prey abundances in the unvegetated areas. Although the relative quality of food resources (i.e., composition, caloric value) is not known for our sample sites, differences in sediment grain size and accumulation of detritus among tidal creeks, mosquito-control ditches, and stormwater-drainage ditches suggest differences in food availability [(i.e., infaunal community (Snelgrove, 1999) and detritus (Krebs, unpubl. data)] that may affect habitat use by juvenile blue crabs. Whether predation mortality differs among the habitat types examined in our study is unknown. However, several species which were collected in considerable abundance in our study sites (Krebs et al., 2007) have been implicated as potential predators on juvenile blue crabs (Guillory et al., 2001). Of these predators, fewer sheepshead *Archosargus probatocephalus* (Walbaum, 1792), pinfish *Lagodon rhomboids* (Linnaeus, 1766), spot *Leiostomus xanthurus* Lacépède, 1802, and red drum *Sciaenops ocellatus* (Linnaeus, 1766) were collected in mosquito-control ditches than in tidal creeks and stormwater-drainage ditches (Krebs et al., 2007), consistent with a hypothesis of lower predation pressure in mosquito-control ditches.

Regardless of the mechanism(s) underlying habitat use by juvenile blue crabs, comparison of densities among studies is important, but complicated by gear efficiency differences. Recent studies conducted in a variety of habitats report a wide range of densities for juvenile blue crabs (Table 1) and, predictably, researchers have reached differing conclusions. Using lift nets, Caudill (2005) observed that blue crabs were more closely associated with mangroves than saltmarshes in Caminada Bay, Louisiana. Alternatively, studies utilizing drop samplers or suction samplers (Orth and van Montfrans, 1987; Thomas et al., 1990; Williams et al., 1990; Wilson et al., 1990; Sheridan, 1992) reported densities that were generally one order of magnitude greater in saltmarsh, seagrass, and openwater habitats than the densities observed along mangroves by Caudill (2005) and during our study. The lower observed densities in our study could be related to gear such as seines being less efficient at catching macroinvertebrates than drop samplers (Freeman et al., 1984). Some of the lowest reported densities of juvenile blue crabs are from an intertidal marsh at Sapelo Island, Georgia, where block nets were used to capture blue crabs exiting tidally drained creeks (Fitz and Wiegert, 1991). Clearly, comparative studies of habitat use employing similar methods to sample mangrove, saltmarsh, and seagrass habitats are needed to better understand the relative value of mangrove wetlands in supporting juvenile blue crabs.

The results of our study have important implications for management of mangrove wetlands and proposed restoration projects. The removal of stormwater-drainage ditches and restoration of more natural flow to the creek at Mobbly Bayou (upper bay) should have no negative impact on local blue crab numbers. Densities of juvenile blue crabs in stormwater-drainage ditches in the upper bay were consistently lowest compared to the other two channel types there. The features of these stormwater-drainage ditches (coarse, shell-hash substrates, relatively little detritus, relatively high densities of potential predators, relatively high current velocities) are apparently less favorable for juvenile blue crabs than conditions in tidal creeks or mosquito-control ditches. However, filling in mosquito-control ditches at that site may reduce the

Table 1. Literature-reported estimates of juvenile blue crab density in various habitat types. Density values were reported as monthly means unless otherwise noted. * = Seasonal mean. SAV = submerged aquatic vegetation.

Habitat	Density (crabs/100 m^2)	Carapace width (mm)	Sampling gear	Study
Unvegetated	10–560	< 40	drop sampler	Thomas et al., 1990
Unvegetated	70	≤103	suction sampler	Wilson et al., 1990
Unvegetated	0 – < 100	< 40	suction sampler	Williams et al., 1990
Saltmarsh	0 – > 0.5	≤ 80	block net	Fitz and Wiegert, 1991
Saltmarsh	130–2,210	< 40	drop sampler	Thomas et al., 1990
Saltmarsh	10–800	< 102	suction sampler	Orth and van Montfrans, 1987
Saltmarsh	80	≤ 103	suction sampler	Wilson et al., 1990
SAV	280–5,060	< 40	drop sampler	Thomas et al., 1990
SAV	< 300–9,000	< 102	suction sampler	Orth and van Montfrans, 1987
SAV	60	≤103	suction sampler	Wilson et al., 1990
SAV	< 200–3,650	< 50	suction sampler	Williams et al., 1990
Mangrove	15–81*	< 30	drop sampler	Sheridan, 1992
Mangrove	33–45*	< 80	lift net	Caudill, 2005
Mangrove	0.2–47*	< 80	seine with block nets	Yeager et al., 2007, this study
Mangrove/saltmarsh transition	28*	< 70	lift net	Caudill, 2005
Macroalgae	70	≤ 103	suction sampler	Wilson et al., 1990

extent of an important juvenile habitat. In contrast, restoration of mosquito-control ditches at Weedon Island (mid bay) may have little effect on the juvenile blue crab numbers because densities in this habitat were consistently low.

Differential habitat use by juvenile blue crabs is likely due to an interaction of habitat characteristics, spatial arrangement of habitat types relative to estuarine circulation patterns, and possibly to differences in survival among habitats. Our results emphasize the importance of considering both habitat characteristics and spatial location when determining relative value of natural and altered mangrove wetlands.

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