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Beach Debris Causing Death of Land Hermit Crabs (Anomura, Coenobitidae)

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Anthropogenic debris is a critical environmental issue, particularly in marine and coastal areas. The lives of animals are inevitably impacted by items discarded by humans, unintentionally or intentionally transported to coastal environments (Napper & Thompson, 2020). Marine animals' ingestion of, or entanglement in, non-biodegradable debris, including discarded fishing gear, often resulting in death (so-called as "ghost fishing"; Carr & Harris, 1997; Laist, 1997; Gall & Thompson, 2015; NOAA Marine Debris Program, 2015), is a major problem. Impacts have mostly been noted among large- and medium-sized animals such as marine mammals, sea turtles, sea birds and fishes (Kuhn *et al.*, 2015; de Carvalho-Souza *et al.*, 2018). Less attention has been paid to small animals, particularly invertebrates, including crustaceans. Most reports on the effects of anthropogenic debris on crustaceans are related to commercial species entrapped in discarded fishing gear, such as blue crabs *Callinectes sapidus* Rathbun, 1896, blue swimming crab *Portunus pelagicus* (Linnaeus, 1758), dungeness crab *Metacarcinus magister* (Dana, 1852), American lobster *Homarus americanus* H. Milne Edwards, 1837, and Norway lobster *Nephrops norvegicus* (Linnaeus, 1758) (Campbell & Sumpton, 2009; DelBene *et al.*, 2019; Lively & Good, 2019).

Land hermit crabs of the genus *Coenobita* (Anomura, Coenobitidae) play a critical ecological role as generalist scavengers in supralittoral coastal habitats, accelerating the rate of recycling of nutrients and energy transfer in the food chain (Laidre, 2013). These hermit crabs normally occupy discarded gastropod shells which protect their soft and fragile abdomen from predators and environmental stresses (Wolcott, 1988; Greenaway, 2003). Increasing quantities of anthropogenically-generated debris in coastal environments results in negative interactions between land hermit crabs and the debris. There are many documented reports of land hermit crabs adopting beach debris instead of traditional gastropod shells as their shelters. *Coenobita brevimanus* in Thailand used a piece of broken glass as its mobile shelter (Thongtham, 1999). *C. perlatus* occupied plastic debris in Maldives (Barreiros & Luiz Jr, 2008). *C. compressus* utilized parts of bottles for their shelters in Costa Rica (Laidre & Vermeij, 2012). *C. clypeatus* wore a plastic container in Belize (Sharma, 2018). The consequences, if any, of use of unsightly unnatural objects as mobile homes by hermit crabs are still not clearly understood. Nevertheless, recent laboratory studies indicated potential negative effects: the leaching of the plastic additive oleamide from marine debris apparently attracts the hermit crab *Pagurus bernhardus* due to its molecular resemblance to food (Greenshields *et al.*, 2021). In addition, *P. bernhardus* exposed to polyethylene microplastics showed impaired shell selection, spending longer time to contact and enter optimal shells than those in the control group (Crump *et al.*, 2020). Furthermore, microplastic exposure significantly influenced

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the attack and defence abilities of *P. bernhardus* during shell contests (CUNNINGHAM *ET AL.*, 2021). Another example of deleterious threat from anthropogenic debris is the recently reported deaths of marine hermit crabs entrapped in waste tires in Japan (SOGABE & TAKATSUJI, 2021). Most recently, LAVERS *ET AL.* (2020) reported entrapment and significant mortality in beach debris among *C. perlatus* from two oceanic atolls, Cocos (Keeling) Islands in the Indo-West Pacific and Henderson Island in the South Pacific.

The present observations document the negative impact of beach debris resulting in death of land hermit crabs on Phuket Island on the Andaman Coast of Thailand. The author found carcasses of land hermit crabs entrapped inside beach debris during a study on the population ecology and shell utilization of the land hermit crabs *Coenobita rugosus* and *C. violascens* at Cape Panwa, Phuket Island, Thailand, during January 2011 to March 2012 (BUNDHITWONGRUT *ET AL.*, 2014, 2015; BUNDHITWONGRUT, 2018a). Three discarded beverage bottles (one glass and two plastic) were found among the vegetation and leaf litter in the supralittoral zone during low tide in 1×1-m sampling quadrats. A total areas of 240 m^2 was sampled over a period of 45 days. Two bottles contained dead land hermit crabs and empty gastropod shells, whereas another contained only empty gastropod shells. Land hermit crab species and gastropod shell families were identified, and their numbers were recorded (Table 1). One 450-ml plastic bottle held six dry bodies of *C. rugosus* and two empty gastropod shells (genus *Nerita*) on 17 February 2011 (Figs.1A, E). The glass beverage bottle (250 ml) contained nine old and worn empty gastropod shells (mostly Neritidae) on 21 February 2011 (Fig.1B). Carcasses of land hermit crabs were not found inside in this container, but ants were encountered around the bottle (Fig. 1D). Thirdly, another plastic drink bottle (1500 ml) contained about 18 decomposed bodies of *C. rugosus* and 18 empty gastropod shells (including nine neritid shells), observed on 13 May 2011 (Fig. 1C).

Although vegetation in supralittoral habitats provides significant shelters for land hermit crabs (BROOK *ET AL.*, 2009; BUNDHITWONGRUT *ET AL.*, 2014), discarded debris accumulates

Table 1. Date, debris type and size, identity and numbers of entrapped land hermit crabs and empty gastropod shells, occurrence of ants and remarks of beach debris found in quadrat samplings during current observations from January 2011 to March 2012. The numbers of entrapped land hermit crabs and empty gastropod shells are shown in parentheses.

Date	Debris		Species and number of entrapped land hermit crabs	Family and number of entrapped gastropod shells	Occurrence of ants	Remarks
	Type	Size (ml)				
17 Feb. 2011	plastic beverage bottle	450	*Coenobita rugosus* (6)	Neritidae (2)	absent	-
21 Feb. 2011	glass beverage bottle	250	-	Neritidae (8) Turbinidae (1)	present	crab carcass not found
13 May 2011	plastic drink bottle	1500	*Coenobita rugosus* (18)	Neritidae (9) Cerithiidae (5) Muricidae (2) Littorinidae (1) Turbinidae (1)	absent	most crab carcasses decomposed and disintegrated

Figure 1. Beach debris found during the present observations at Cape Panwa, Phuket Island, Thailand: A, The plastic beverage bottle (450 ml) found on 17 February 2011; B, The glass beverage bottle (250 ml) found on 21 February 2011; C, The plastic drinking bottle (1500 ml) found on 13 May 2011; D, ants around the trashed glass bottle and empty gastropod shells inside the bottle found at Cape Panwa, Phuket Island, Thailand on 21 February 2011; E, dead individuals of *Coenobita rugosus* and empty gastropod shells inside the plastic bottle found at Cape Panwa, Phuket Island, Thailand on 17 February 2011. Photos by Thanakhom Bundhitwongrut.

among the vegetation. Consequently, there are opportunities for crabs to become entrapped in the bottles. The increase in crab mortality probably results in decline in population abundance. The mortality of *C. rugosus* entrapped in beach debris might seem low compared with the density of this species (6.98 ± 0.36 crabs/m^2) investigated by BUNDHITWONGRUT *ET AL.* (2014). Nevertheless, this might not reflect the actual number of dead crabs caused by the entrapment at the study site because of effect of small-sized sampling quadrats used (BUNDHITWONGRUT *ET AL.*, 2014). Therefore, a larger quadrat size covering more diverse habitats, particularly beach vegetation, as used by LAVERS *ET AL.* (2020), and longer study period should be utilized to better estimate the actual number of hermit crabs threatened by exposure to beach debris. Furthermore, only three cases of hermit crab trap mortality at this site were found in a rather short period of time (February to May 2011), and it is possible that trashed bottles exhibit seasonality due to the weather at this location. Nevertheless, at this site juveniles of *C. rugosus* occur in all months and the recruitment of larvae seems to occur throughout the year, as ovigerous females are found year-round (BUNDHITWONGRUT *ET AL.*, 2014).

Land hermit crabs moving into trashed bottles may be unable to escape. Either water or food items may entice hermit crabs to enter the bottles. The discarded bottles presumably trap freshwater during rain, or saltwater when carried to the beach by waves. Moreover, the bottles may also trap dietary items such as animal carcasses (including dead conspecifics), plant debris or other organic matter (see also BUNDHITWONGRUT *ET AL*. [2014] for the diet of *C. rugosus* at the study site). The limited space inside the bottles might lead crabs to fight for such resources or to compete in order to escape from the containers. High daytime temperature inside the bottles may further lead to the death of entrapped crabs.

Although three species of land hermit crabs inhabit the present site (BUNDHITWONGRUT *ET AL.*, 2014), only dead *C. rugosus*, the most abundant species, were found. Moreover, most of the empty gastropod shells entrapped were neritid shells, which are most utilized by *C. rugosus* (BUNDHITWONGRUT *ET AL.*, 2015). The odor of dead hermit crabs attracts other conspecific individuals to locate shell(s) of dead individual(s) (SMALL & THACKER, 1994). Each hermit crab species probably uses different specific olfactory clues. Further investigations are needed to clarify this point.

Although competition for food exists between land hermit crabs and ants in insular environments, ants do not kill hermit crabs, but rather compete with and repel them from food sources (MORRISON, 2002; MCNATTY *ET AL.*, 2009). Additionally, the odor of dead crabs presumably attracts other animals such as ants which scavenge dead crabs and consume their carcasses. All the shells found in the bottles were in worn and old condition similar to those of "remodeled shells" normally occupied by land hermit crabs, previously reported by LAIDRE (2012a, b). Remodeled shells are gastropod shells altered by land hermit crabs by still unknown mechanisms (probably excretory products, specialized chemical secretions, or bodily abrading of the shell interior), resulting in a worn and old appearance, but lighter in weight and more spacious internally (LAIDRE, 2012a). Therefore, the shells found in the bottle without a crab carcass are potentially occupied shells of dead hermit crabs.

An indirect effect of the shells inside bottles is their unavailability for use by other hermit crabs in the population. Normally, empty shells available for use are a scarce resource under natural conditions (BALL, 1972; LAIDRE & VERMEIJ, 2012), including those at the present study site (BUNDHITWONGRUT *ET AL.*, 2015). Land hermit crabs mostly depend on shell circulation within the population through shell exchange with other individuals (ABRAMS, 1978). Therefore,

a decline in shell availability through bottle entrapment may pose a further indirect threat to crab populations.

This is the first formal report on death of land hermit crabs caused by entrapment in beach debris on a continental island, following an investigation of the same issue from oceanic atolls by Lavers *et al.* (2020). This suggests that such effects of anthropogenic debris on land hermit crabs potentially occur throughout their distributional range. Additionally, in Thailand, land hermit crabs are already facing heavy, unregulated exploitation from the pet trade (Bundhitwongrut, 2018b, 2020). Both are likely causing a decline in abundance of these crabs. Consequently, we need urgent cooperation, as suggested by Bundhitwongrut (2018b, 2020), to mitigate these problems and to preserve these creatures for our next generations.

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