Pacific Invasives Initiative

LAND CRAB INTERFERENCE WITH ERADICATION PROJECTS

PHASE I – COMPENDIUM OF AVAILABLE INFORMATION

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ABSTRACT

Invasive mammal eradications are a proven, effective method of restoring damaged ecosystems and preserving biodiversity. On most tropical oceanic islands indigenous land crabs compete with targeted alien species for bait and interfere with traps and detection devices. Current eradication practices are inherited from successful temperate or subantarctic campaigns, yet we do not possess trued and tried methods for managing land crab interference. This report is the first organized attempt to address what's now commonly referred to as "the land crab problem." Accounts of land crab interference with eradication projects were sourced from an array of eradication practitioners; the resulting information was sorted into major topics and presented in tables, figures, and text. Major topics include: bait application rates, land crab and rat bait consumption, land crab behaviour, land crab interference with bait-stations, land crab deterring bait masks, and toxin exposure risk for non-target species. The summarized information in this report will guide future investigations into the land crab problem.

INTRODUCTION

Invasive mammal eradications are a proven, effective method of restoring damaged ecosystems and preserving biodiversity. With the exception of projects targeting cats (Nogales et al. 2004), most attempts to eradicate mammals from islands were in temperate or subantarctic regions (Campbell and Donlan 2005; Howald et al. 2007), and many of the lessons learned from such operations have been incorporated into programmatic eradication campaigns(such as in New Zealand).

Tropical oceanic islands pose a further challenge to eradication projects, and especially eradications targeting rodents, where indigenous land crabs compete with target species for bait and interfere with traps and detection devices. Because current eradication practices are inherited from successful temperate or subantarctic campaigns, we do not possess trued and tried methods for managing land crab interference. This compendium of information on land crab interference with eradication projects is the first of two steps to significantly decrease this knowledge gap. Our aim is to develop a unified approach to solving what's commonly referred to as "the land crab problem."

In November of 2007, Pacific Invasives Initiative (PII) and NZ Department of Conservation (DOC) circulated a request for information about land crabs as they relate to eradication projects. PII contracted Island Conservation Canada (ICC) to summarize the gathered information. Informative responses (emails) were gathered from 12 individuals representing 10 conservation organizations spanning 8 regions. Here we summarize the gathered information by answering the following 4 questions:

1. Which crab species are known to be interfering with eradication projects?

2. What is the general biology of the land crab species that are known to interfere with eradication projects?

3. What baits were used in operations on islands with land crabs, and to what extent did the crabs interfere with the bait, and what attempts were made to mitigate this interference?

4. What are the major issues and questions regarding land crab interference with eradication projects?

METHODS

Submitted accounts of land crab interference with eradication projects were compiled by DOC and passed to ICC. ICC sorted the information into 4 tables, 1 appendix, and 4 figures, and added the accompanying text. Outside sources (books and journal articles) were referenced to augment or substantiate information mined from the submitted accounts. Whenever possible, information presented in this report was linked to the contributing individual.

RESULTS

1. Which land crab species are known to interfere with eradication projects?

The land crab grouping encompasses 10 families that show significant behavioural, morphological, physiological, or biochemical adaptation allowing for extended activity in the terrestrial environment. Of the 10 families, only 3 establish inland of the littoral zone: Coenobitidae, Gecarcinidae, and Grapsidae (Burggren and McMahon 1988). The gathered information includes discussion of 4 land crab families (Table 1). Land crabs in the families Grapsidae and Ocypodidae do not regularly interfere with applied bait, traps, or detection devices; therefore, the remainder of this report focuses on land crabs in the families Coenobitidae and Gecarcinidae. The submitted reports document 14 species from 6 genera as crabs that interfere with eradication projects (Figure 1); however, it is safe to assume that all members of Coenobitidae (13 sp) and Gecarcinidae (18 sp) (Burggren and McMahon 1988) are capable of such interference.

Table 1: Land crabs encountered on islands discussed in this report and their relevance to bait-based eradication projects

Common name	*Family*	*Genus*	*Species*	*Bait consumer*	*Bait-station* interference*
Coconut crab	Coenobitidae	*Birgus*	*latro*	yes	high
Hermit crabs		*Coenobita*	*brevimanus*	yes	moderate
			cavipes	yes	moderate
			perlatus	yes	moderate
Burrowing land crabs	Gecarcinidae	*Cardisoma*	*carnifex*	yes	low
			hirtipes	yes	low
			guanhumi	yes	low
			longipes	yes	low
			rotundum	yes	low
		Epigrapsus	*Notatus*	yes	low
		Gecarcinus	*lateralis*	yes	low
			planatus	yes	low
			ruricola	yes	low
		Gecarcoidia	*lalandei*	yes	low
Predatory land crabs	Grapsidae	*Geograpsus*	*crinipes*	no	none
			grayi	no	none
Fiddler crabs	Ocypodidae	*Uca*	spp	no	none
Ghost crabs		*Ocypode*	spp	no	none

* Assuming bait-stations are robust, raised, and anchored

2. What is the general biology of the land crab species that are known to interfere with eradication projects?

Varying ranges, habitats, and habits apply to the 6 land crab genera that interfere with eradication projects (Table 2). The breadth of variation in habitat and behavior between the land crab genera poses a significant challenge to eradication campaigns in that mitigation efforts will likely be tailored to specific genera; when more than one genus is present, multiple mitigation approaches will be required.

Table 2: Range, habitat, and habit of land crab genera that commonly interfere with eradication projects. Information on *Birgus*, *Coenobita* and *Epigrapsus* was taken from Burggren and McMahon (1988). Information on *Cardisoma*, *Gecarcinus*, and *Gecarcoidea* was taken from Bright and Hogue (1972).

Genus	*Range*	*Approximate adult size (g)*	*Habitat*	*Habit*
Birgus	Tropical Indo-Pacific	1500, up to 3000	Inhabits wet, forested areas inland to 6 km	Digs shallow burrows for mating and molting, is omnivorous and scavenges carcasses, will climb trees to access food or escape, can live to 70 years

Genus	*Range*	*Approximate adult size (g)*	*Habitat*	*Habit*
Coenobita	East Africa, Indo-Pacific to West coast of the Americas form California to Chile, Australia, East coast of the Americas from Florida to Venezuela, Tropical Atlantic Islands, West Africa, the Red Sea	50 - 200	Inhabits dry to wet forests, grasslands, and rocky islands.	Mainly nocturnal, though less so in humid regions. Use of a gastropod shell or other casing to protect unarmored abdomen and retain water against desiccation. Found from high water line to 15 km, and from the beach to 900 m in elevation, but most species are littoral. Omnivorous and scavenging
Cardisoma	Tropical America, Cape Verde Islands, west coast of Africa, Indo-Pacific from Port St. Johns, Africa to Hawaiian Islands	500 - 700	Commonly inhabits muddy shores, mangrove swamps and saline lowland soils near the coast	Constructs well defined deep burrows in soft soils where ground water is available during the dry season. Commonly plugs the burrow mouth with mud during the dry season to keep the lower portions of the burrow moist. Burrow sites are always above the mean high tide level. They return to the sea to spawn. All species are primarily herbivorous but also feed on carrion
Epigrapsus	Tropical Indo-Pacific	200 - 400	Inhabits stony areas close to the waterline	Unknown
Gecarcinus	Tropical America, Bermudas, Ascension Island, West and South Africa, Australasia	200 - 400	Inhabits drier areas above the tidal margins of mangroves; river mouths and adjacent coastal sandy and saline soil areas	Burrows always shallow and devoid of ground water, except during rain storms. Many utilize debris as a source of protection in lieu of a burrow. In the extreme northern and southern portions of the distribution the burrows are deep 1.2 m and often with mouth plugged during the dry season
Gecarcoidea	Indo-Pacific Islands	200 - 300	Inhabits areas with moist soil or muddy areas in the jungle, and areas adjacent to the sea	Burrows are shallow and not well developed

Following is a series of extracts from Burggren and McMahon's (1988) compilation of articles on land crab biology. The bulleted notes are paraphrases from the book; the italicized sub-bullets are comments connecting the excerpts to land crab interference with eradication projects. The excerpts sort into the following categories: distribution and density, land crabs and toxins, foraging ecology, and reproduction.

DISTRIBUTION AND DENSITY

- The Indo-West Pacific has the highest diversity of land crabs.
    - *A diverse land crab community increases the mitigation challenge for eradication projects. For example, burrowing land crabs generally do not interfere with bait-stations, while Coenobitas and Birgus do; a mixture of burrowing species and Coenobitas and/or Birgus could require heavy application rates for a bait broadcast, or complicated and potentially rat-limiting bait-station designs.*
- Land crabs are generally tropical, extending in smaller numbers into subtropical and warm temperate areas, but mostly excluded from cooler zones.
    - *Land crab interference with eradication efforts is a serious challenge unique to the tropics, thus eradication projects on tropical islands should not be strictly modeled after eradication projects on islands outside of the tropics and without land crabs.*
- Land crabs can reach astonishing densities in the absence of heavy predation and, on islands with scarce mammalian and avian fauna, can be the dominant fauna. On Aldabra - *Cardisoma carnifex* can reach densities of over 3,600 per hectare, with an average individual mass of 322g.
    - *In a broadcast scenario, if the average C. carnifex consumes 10 g of bait in an evening (see below), this density of crabs is capable of consuming 36 k/ha/day. To maintain bait on the ground for a minimum of 3 days (see below), the requisite application rate would have to be in excess of 108 k/ha alongside the amount necessary to reach every rat in every rat territory.*

LAND CRABS AND TOXINS

- Because of its large size, excellent meat, and fatty abdomen, *Birgus latro* is highly esteemed as food and consequently is rare on all inhabited islands.
    - *Human consumption of* B. latro *and other land crabs both assists and complicates eradication campaigns by effectively reducing land crab densities and opening a pathway for human exposure to eradication related toxins.*
- Humans are among the most influential predators of some land crab species.

- *Toxin-based eradication project on islands with permanent human settlements must mitigate for the risk of human exposure to toxins through the consumption of land crabs.*

- A large *Birgus latro* was observed feeding on a smaller one that it had caught and dismembered, and tethered *B. latro* are often attacked and eaten by free ranging *B. latro*. *B. latro* requires animal protein in the laboratory, and is thought to prey on other land crabs in natural settings.

    - *Toxins used in eradication projects can be transferred laterally to crabs that do not consume bait, but prey on other crabs that have consumed bait.*

- Shore-feeding fishes take adult *Cardisoma carnifex*.

    - *An obscure but possible toxin pathway from bait application to land crab to fish.*

FORAGING ECOLOGY

- *Coenobitas* are generally tolerant of each other, and will feed gregariously when food is plentiful.

    - *The social proclivity of Coenobitas allows high-density feeding aggregates that can monopolize dense pockets of bait following an uneven broadcast. Also, the stacking behavior that challenges the design of a crab-proof bait-station is a product of this social behavior.*

- Land crabs have two basic foraging modes. The more lightly armored crabs that depend on speed and agility for defense tend to be active predators and facultative scavengers. Heavily armored crabs are usually more sluggish and tend to feed mostly on inactive items; since there are few sessile animals on land, these crabs are primarily herbivores or detritivores; most of these herbivores / detritivores also scavenge carrion whenever possible. *Coenobitas* scavenge carrion so effectively that they are thought to be one reason for the low numbers of carrion-breeding flies on Pacific islands.

    - *As carrion scavengers, land crabs are at risk of exposure to toxins during eradication campaigns. If the toxin is an anticoagulant, the crab will not be harmed; however, the crab will then become a secondary pathway for the exposure of anything that preys on or otherwise consumes the crab.*

- *Birgus latro* forages 30 m or more from its burrow

    - B. latro *is generally rare throughout it's range (see below); however, this species is disproportionately capable of robbing or dismantling bait-stations. Because* B. latro *forages far from its burrows, and in fact can have several burrows within its territory, each bait-station will likely be subject to attacks from more than one individual.*

- *Birgus latro* is capable of exerting about 1.5 times the force of a human bite and can shear sticks up to 5 cm in diameter.

    - Birgus latro's *strength is another deterrent from using bait-stations in the presence of this species. Large* B. latros *will rip apart 5-gallon plastic buckets and demolish Protecta® bait-stations to access the enclosed bait.*

- *Birgus latro* on Christmas Island (Indian Ocean) exhibited limited diurnal activity when nocturnal rats were common, presumably because of reduced predation by, and competition with rats. After rat control, *Birgus latro* returned to nocturnal foraging.

    - *It may be the case that rat predation of land crabs and direct competition for resources has led to a shared, but temporally divided niche space; land crabs will not be directly competing with rats for bait if they are more diurnal and the rats nocturnal. In a broadcast scenario, bait applied during the day could be subject to several hours of crab foraging before most rats become active (this was the case at Palmyra Atoll).*

- *Cardisoma* "taste" objects in the environment by touching the minor chela to the object and then to the mouthparts, which suggests contact chemoreception is important in initiating a feeding response.

    - *A bait mask, or bait flavored with an ingredient that is both attractive to rats and repulsive to crabs could almost entirely solve the land crab bait consumption issue; however, different crab genera, or possibly species, might not be similarly repulsed by a given taste.*

- *Cardisoma* either eat an item immediately or quickly remove it to their burrow.
    - *Cardisoma can increase bait take through hording bait in burrows. The rate at which this occurs, and whether or not the bait is permanently rendered unavailable to rats warrants investigation.*

REPRODUCTION

- Breeding is typically cyclic, with lunar or semi lunar rhythms peaking near the spring tides. Reproduction can occur year round in the tropics, and can also depend on variation in rainfall.

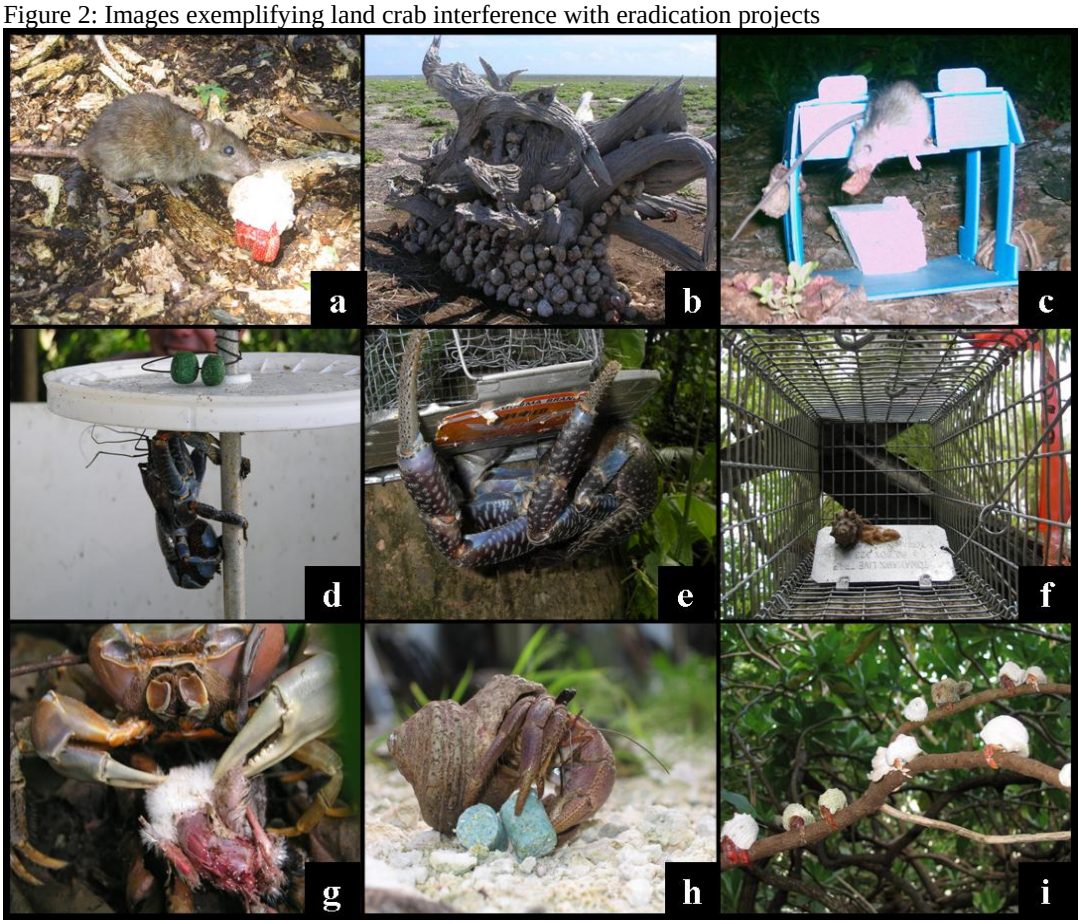
    - *The aseasonality of land crab breeding (and molting) makes it difficult to time eradication projects during periods of "low" land crab abundance.*

Figure 1: Key to the land crab species discussed in this report

3. What baits were used in operations on islands with land crabs, and to what extent did the crabs interfere with the bait, and what attempts were made to mitigate this interference?

Only 4 of the 14 responses to the request for information on land crab interference with eradication projects included mention of bait manufacturer and bait pellet size (Table 3). More information is needed from past and present projects to form hypotheses let alone draw conclusions about pellet size and bait formulation relevance to crab interference.

Figure 2: Images exemplifying land crab interference with eradication projects



a. *R. rattus* attacking *C. perlatus* at Palmyra Atoll; land crab carapace pieces are common items in rat husking stations – rodenticide toxins can move through land crabs to rats or non-target species (Island Conservation)
b. *C. perlatus* pile in the Phoenix Islands; *Coenobita* will pile to access desired resources, ranging from shade to bait in a bait-station (R. Pierce – Eco Oceania Ltd)
c. R. rattus with a chunk of coconut exiting a Rat-Go® bait-station while *C. brevimanus* attempt to enter the station at Palmyra Atoll; bait stations that provide an overhanging entrance are more robust against land crab interference (Island Conservation)
d. *B. latro* testing an experimental bait-station at Palmyra Atoll; the crab eventually accessed the bait - designing a crab-proof bait-station that is also accessible to all individuals of the target population is a serious challenge (D. Vice - USDA).

e. A small *B. latro* disabling a tree-mounted Hagaruma® rat trap at Pohnpei; land crabs frequently interfere with trapping efforts – elevating traps on plastic buckets or mounting them to trees will discourage all but the most determined crabs (Island Conservation).
f. A small *C. brevimanus* avoids entrapment while consuming peanut butter bait from a Tomahawk® rat trap at Pohnpei; small crabs, especially *Coenibitids*, readily rob bait from live-capture traps; elevating traps and checking trigger sensitivity can all but eliminate this problem (Island Conservation)
g. An adult *Cardisoma carnifex* consumes a Sooty Tern (*Sterna fuscata*) chick at Palmyra Atoll; gecarcinids and coenibitids are capable scavengers, and will readily consume rat carcasses – land crabs experience indirect exposure to rodenticides through scavenging carcasses (Island Conservation)
h. An adult *Coenobita brevimanus* consumes one 2.3 gram bait pellet while hording another at Palmyra Atoll (Island Conservation)
i. *Coenobita perlatus* resting on *Tournefortia argentea* branches at Palmyra Atoll; All *Coenibitids* including *B. latro*, are proficient climbers; if elevating bait-stations or traps by securing them to trees, select large-stemmed, smooth-barked trees (Island Conservation).

Reports of land crab interference with bait or bait stations is exemplified in Figure 2, and presented in Table 3. Direct competition for bait was the most commonly reported type of interference. Summary statistics from 3 bait removal trials (Palmyra Atoll, Vahanga Atoll, Phoenix Is.) are presented in Table 4. Reported daily bait consumption values for individual crabs range from 3.7 g/day for *Cardisoma sp* (Howald et al. 2004), to 10 g/day for *Coenobita* sp. (Thorsen 2007). Reports of land crab interference with bait-stations primarily involved *Coenobita* and refer to social aggregations and piling behavior (Table 3, Figure 2.b. and Figure 3).

Reported attempts to mitigate land crab interference involve increased bait application rates (9 mentions) and use of bait-stations (11 mentions) (Table 3).

Fig 3: Hermit crab consumption of non-toxic bait at McKean Island, Phoenix Islands (Ray Pierce 2007).

Table 3: Compiled data from submitted accounts of land crab interference with eradication projects. Information is divided between project islands and target species, e.g. one project island with 2 target species is presented in two rows – one row for each species. Abbreviations stand for the following terms: Island Type: HD = high and dry, HW = high and wet, LD = low and dry, LW = low and wet; Project description: E = eradication, FS = feasibility study; Project successful: Y = yes, Y-P = yes-pending, N = no; Species targeted: F.c. = *Felis catus*, H.a. = *Herpestes auropunctatus*, M.m. = *Mus musculus*, R.e. = *Rattus exulans*, R.n. = *R. norvegicus*, R.r. = *Rattus rattus*; Method used: b-s = bait-station, h-b = hand broadcast, t = trapping; Land crab genus: B = *Birgus*, Ca = *Cardisoma*, Co = *Coenobita*, Ge = *Gecarcinus*; Gec = Gecarcoidia; Toxin used: Dipha = diphacinone, Brom = bromadiolone, Brod = brodifacoum, Pl = placebo, Chlor = chlorophacinone.

Island Group	Island name	Island type	Island size (ha)	Project description	Project successful?	Species targeted	Method used	Land crab genus	Are crabs a problem?	Toxin used	Bait manufacturer	Bait pellet size (g)	Application rate	Bait interference?	Land crab mitigation attempt	Land crab response	Mitigation successful
Atlantic: Brian Bell - Wildlife Mangement International Limited																	
Ascension	Ascension	HD	9100	E	y	F.c.	b-s	na	y	1080	na	na	na	y	4 liter buckets filled with sand	only largest crabs had access	y
Caribbean: Earl Campbell - US Fish & Wildlife Service; Michel Pascal - INRA - Equipe Gestion des Populations Invasives																	
US Virgin Is.	Buck Is	LD	71	E	y	R.r.	b-s	Ca, Co	y	Dipha	na	na	na	u	bait-stations	na	y
Martinique	Perce	LD	1	E	y	R.r.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Poirier	LD	2	E	y	R.r.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Hardy	LD	3	E	y	R.r.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Guadeloupe	Fajou	LD	120	E	n	R.r.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Perce	LD	1	E	u	M.m	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Poirier	LD	2	E	u	M.m	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Hardy	LD	3	E	u	M.m	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n

Island Group	Island name	Island type	Island size (ha)	Project description	Project successful?	Species targeted	Method used	Land crab genus	Are crabs a problem?	Toxin used	Bait manufacturer	Bait pellet size (g)	Application rate	Bait interference?	Land crab mitigation attempt	Land crab response	Mitigation successful
Guadeloupe	Fajou	LD	120	E	u	M.m	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Perce	LD	1	E	u	H.a.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Poirier	LD	2	E	u	H.a.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Martinique	Hardy	LD	3	E	u	H.a.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Guadeloupe	Fajou	LD	120	E	u	H.a.	h-b & t	Co	y	Brom	na	na	na	y	none	Co entered traps and stole baits, Ge tripped traps	n
Central Pacific: Mike Thorsen - Otago Conservancy; Stacey Buckelew - Island Conservation; Michel Pascal - INRA - Equipe Gestion des Populations Invasives; Ray Pierce - Eco Oceania Ltd																	
Phoenix	unspecified	LD	2760	E	u	R.t.	b-s	Ca, Co	y	na	na	na	na	y	use of raised bait stations	Co piled up in front of hole to gain access to bait	n
Phoenix	unspecified	LD	2761	E	u	R.e.	b-s	Ca, Co	y	na	na	na	na	y	use of raised bait stations	Co piled up in front of hole to gain access to bait	n
Line	Palmyra	LW	5	E	y	R.r.	h-b	Ca, Co, B	y	Brod	Bell	2..3	70-96	y	high application rate and canopy baiting	crab related bait consumption assumed high	y
Line	Palmyra	LW	223	E	n	R.r.	b-s	Ca, Co, B	Y	Brod & others	unk	unk	50m grid	Y	modified bait-stations	Reduced but continued interference with bait-stations	n
Phoenix	McKean	LD	48	FS	na	R.t.	h-b	Co	y	Pl	ACP	10	10	y	none	100% bait consumed during the first	

Island Group	Island name	Island type	Island size (ha)	Project description	Project successful?	Species targeted	Method used	Land crab genus	Are crabs a problem?	Toxin used	Bait manufacturer	Bait pellet size (g)	Application rate	Bait interference?	Land crab mitigation attempt	Land crab response	Mitigation successful
																night	
Phoenix	McKean	LD	49	FS	na	R.t.	h-b	Co	y	Pl	ACP	5	40	y	none	90% of bait consumed during the first night; 100% consumed after the second night	n
Eastern Pacific: Michel Pascal - INRA - Equipe Gestion des Populations Invasives																	
Clipperton	Clipperton	LD	200	E	u	R.r.	na	Ge	y	na	na	na	na	y	undocumented	na	
Clipperton	Clipperton	LD	200	E	u	R.n.	na	Ge	y	na	na	na	na	y	undocumented	na	
Cocos	Cocos	HW	2385	E	u	R.r.	na	Ca, Co	y	na	na	na	na	y	undocumented	na	
Cocos	Cocos	HW	2385	E	u	R.n.	na	Ca, Co	y	na	na	na	na	y	undocumented	na	
Polynesia: Brian Bell - Wildlife Mangement International Limited; Richard Griffiths et al. - NZ Dept. of Conservation, Pacific Invasives Initiative, SOP Manu; Steve Cranwell - BirdLife International; Michel Pascal - INRA - Equipe Gestion des Populations Invasives; Souad Boudjelas - Pacific Invasives Initiative																	
Tuamotus	Pitcairn	HD	500	E	n	R.e.	h-b	na	y	Brod	na	n	na	a	Increased application rate	na	u
Tuamotus	Vahanga	LW	382	FS	na	R.e.	h-b	Co, B	y	Pl	Pestoff	2	10	y	none	na	
Tuamotus	Vahanga	LW	382	FS	na	R.e.	h-b	Co, B	y	Pl	Pestoff	2	20	y	none	na	
Tuamotus	Vahanga	LW	382	FS	na	R.e.	h-b	Co, B	y	Pl	Pestoff	2	30	y	none	na	
Samoa	Aleipata	HW	168	FS	na	R.sp.	b-s	Co	y	none	-	n	-	y	5 liter bucket with hole drilled into side	Co piled up in front of hole to gain access to bait	n
Fiji	Vatuira	LW	60	E	y - p	R.e.	h-b	Co	y	Brod	na	n	na	y	crab related bait removal monitored	Co removed very little bait; rats removed most bait within first few hours of bait-drop	-
Vanuatu	Esperitu Santo	HW	39550	FS	u	R. sp	t	none	n	none	na	n	na	n	no land crab interference	plots far from seashore	
Tuamotus	Vahanga	LW	382	E	n	R.e.	na	Ca, Co	y	Brod, Chlor	na	n	na	y	undocumented	na	n

Island Group	Island name	Island type	Island size (ha)	Project description	Project successful?	Species targeted	Method used	Land crab genus	Are crabs a problem?	Toxin used	Bait manufacturer	Bait pellet size (g)	Application rate	Bait interference?	Land crab mitigation attempt	Land crab response	Mitigation successful
Fiji	Vatuira	LW	60	E	y - p	R.e.	h-b	Co	y	Brod	na		na	y	crab related bait removal monitored	Co removed very little bait; rats removed most bait within first few hours of bait-drop	-
Vanuatu	Esperitu Santo	HW	39550	FS	u	R. sp	t	none	n	none	na		na	n	no land crab interference	plots far from seashore	
Tuamotus	Vahanga	LW	382	E	n	R.e.	na	Ca, Co	y	Brod, Chlor	na		na	y	undocumented	na	n
Indian Ocean: Brian Bell - Wildlife Mangement International Limited; Mike Thorsen - Otago Conservancy																	
Mauritius	Flat	LD	253	E	y	M.m	h-b & b-s	Ca, Co	y	Brod, Brom	na		na	a	Increased application rate	na	y
Mauritius	Flat	LD	254	E	y	R.r.	h-b & b-s	Ge, Co	y	Brod, Brom	na		na	a	Increased application rate	na	y
Mauritius	Gabriel	LD	42	E	y	R.r.	h-b	Ge, Co	y	Brod, Brom	na		na	a	Increased application rate	na	y
Mauritius	Cocos	LD	8	E	y	M.m	b-s	Ge, Co	y	Brod, Brom	na		na	y	25 cm plastic tube - bait stations	Ge took bait stations into burrows and accessed bait	n
Mauritius	Sabel	LD	15	E	y	M.m	b-s	Ge, Co	y	Brod, Brom	na		na	y	25 cm plastic tube - bait stations	Ge took bait stations into burrows and accessed bait	n
Mauritius	Cocos	LD	8	E	y	M.m	b-s	Ge, Co	y	Brod, Brom	na		na	y	Increased application rate	na	y
Mauritius	Sabel	LD	15	E	y	M.m	b-s	Ge, Co	y	Brod, Brom	na		na	y	Increased application rate	na	y
Seychelles	unspecified	LW	430	E	n	R.n.	b-s	Ca, Co	y	Brod	na		na	y	attached bait to bait-station with wire	na	y
Micronesia: Alex Wegmann - Island Conservation; Pete McClellend – NZ Dept of Conservation																	

Island Group	Island name	Island type	Island size (ha)	Project description	Project successful?	Species targeted	Method used	Land crab genus	Are crabs a problem?	Toxin used	Bait manufacturer	Bait pellet size (g)	Application rate	Bait interference?	Land crab mitigation attempt	Land crab response	Mitigation successful
Pohnpei	Dekehtik	LW	3	E	y-p	R.e.	h-b	Gec, Co, B	y	Brod	Bell		50	y	high application rate and canopy baiting	crab related bait consumption assumed high	y
Pohnpei	Nahkapw	LW	2	E	y-p	R.r.	b-s	Gec, Co, B	y	Brod	Bell		20 m grid	y	Rat-Go® bait stations and tree mount wax-based bait stations	Co related bait take was higher in tree stations than Rat-Go® stations, but minor	y
Pohnpei	Pein Mal	LW	2	E	y-p	R.r.	h-b & b-s	Gec, Co, B	y	Brod	Bell		50	y	high application rate, canopy baiting, tree-based bait stations in mangrove forest	minimal crab bait take in mangrove stations while rat related bait take was common	y
Marshall Islands	Wake	LD	760	FS	na	R.e.	b-s	Co	y	none	na		na	y	several bait-station designs	limited to no access	y
Marshall Islands	Wake	LD	761	FS	na	R.t.	b-s	Co	y	none	na		na	y	several bait-station designs	limited to no access	y

Table 4: Summary of bait uptake rates on islands with measured land crab densities

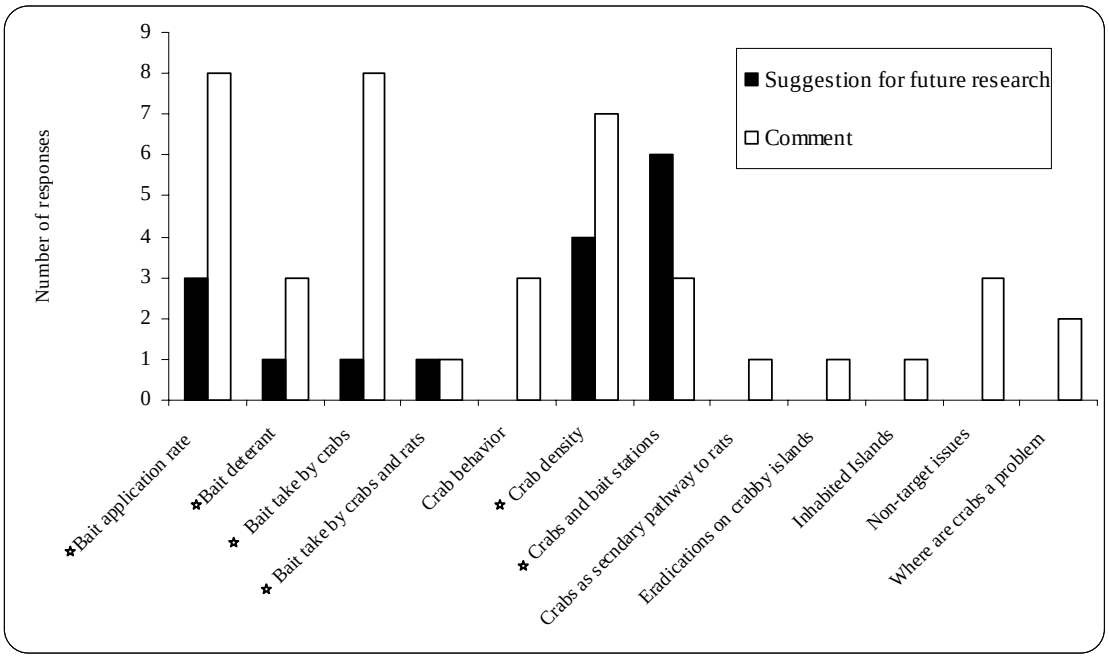
Island	*Application rate*	*Bait size (g)*	*Days post application*	*Bait consumed (kg/ha)*	*Biat remaing (kg/ha)*	*% of application removed*	*Coenobitidae density (crabs/ha)*	*Gecarcinidae (crabs/ha)*	*Potential crab-related bait consumption (kg/ha/day)*
Tuamotus - Vahanga	5	2	1	5	0	100%	2	0	0.02
Tuamotus - Vahanga	15	2	2	15	0	100%	20	0	0.2
Palmyra - Whipporwill	95	2.3	1	30	65	32%	114	31	1.76
Palmyra - Whipporwill	95	2.3	2	47	48	49%	114	31	1.76
Palmyra - Whipporwill	95	2.3	3	63	32	66%	114	31	1.76
Palmyra - Whipporwill	95	2.3	4	76	19	80%	114	31	1.76
Palmyra - Bunker	70	2.3	1	32	38	45%	114	31	1.76
Palmyra - Bunker	70	2.3	2	48	22	69%	114	31	1.76
Palmyra - Bunker	70	2.3	3	53	17	76%	114	31	1.76
Palmyra - Home	85	2.3	1	20	65	24%	114	31	1.76
Palmyra - Home	85	2.3	2	34	51	40%	114	31	1.76
Palmyra - Home	85	2.3	3	36	49	42%	114	31	1.76
Palmyra - Home	85	2.3	4	51	34	60%	114	31	1.76
Palmyra - Aviation	90	2.3	1	42	48	47%	114	31	1.76
Palmyra - Aviation	90	2.3	2	51	39	56%	114	31	1.76
Palmyra - Aviation	90	2.3	3	58	32	64%	114	31	1.76
Palmyra - Aviation	90	2.3	4	65	25	72%	114	31	1.76
Phoenix - McKean	10	10	1	10	0	100%	2000	0	20
Phoenix - McKean	40	5.5	1	32	8	80%	4000	0	40
Phoenix - McKean	40	5.5	2	40	0	100%	4000	0	40

CONCLUSION

4. What are the major issues and questions regarding land crab interference with eradication projects?

Following is a summary of the major topics extracted from the accounts of land crab interference with eradication projects. The frequency at which certain topics were given mention in the accounts is presented in Table 4; topics with high frequency of comments and questions or suggestions for future research are considered priorities for further investigation. All comments and questions contained in the accounts are presented in the Appendix.

Figure 4: Frequency of comments and suggestions for future research by topic from accounts of land crab interference with eradication projects. A ☆ in front of the topic heading indicates that the topic is a priority for further investigation.



APPLICATION RATE / LAND CRAB & RAT BAIT CONSUMPTION

For broadcast eradications, the pursuit of appropriate, project-specific bait application rates is tightly linked to an understanding of the bait consumption potential for both land crabs and rats. However, transferring conclusions from successful application rates employed in temperate and subantarctic eradication campaigns to the tropics is problematic. Consequently, little information is available to gauge what is appropriate for tropical, land crab islands (Table 4 & Appendix). Where pertinent information is available, the amount and rate of bait consumption by land crabs varies per report and per land crab genus. For a given project area, the land crab bait consumption rate will be tied to land crab density. Several methods of measuring land crab density have been proposed and trialed (Appendix). There is a dire need to establish

standardized methods for measuring land crab bait consumption potential, which will include a standardized method for measuring land crab density.

The use of a biomarker to assess application rate efficacy readdresses the primary question, what is the necessary application rate for a given project area, without the complications of estimating land crab density and land crab bait consumption rates. Yet, the results from biomarker trials will not be informative without a baseline understanding of the previous issues, land crab density, and land crab bait consumption. The first biomarker study on a land crab island was recently conducted at Vahanga Atoll, Tuamotu Archipelago (Griffiths et al. 2008); the second biomarker study on a land crab island will be in the summer of 2008 at Palmyra Atoll.

Following is a list of recommendations for further investigation of this topic:

1. Coordinate active eradication project managers in the development of a standardized method for measuring land crab bait consumption rates, g/hour and g/day, for industry standard bait formulations. Rat bait consumption measures can be inferred from eradication campaigns outside of the tropics.

2. Coordinate active eradication project managers in the development of a set of standardized methods for estimating density for burrowing (Gecarcinidae) and non-burrowing (Coenobitidae) land crabs.

3. Summarize results from bait application trials that employ a biomarker to determine application rate efficacy; encourage eradication project managers to conduct biomarker bait studies prior to implementation with active bait.

LAND CRABS AND BAIT STATIONS

Bait-stations are an attractive mitigation strategy for the land crab problem, and several station designs have proven effective at deterring hermit crabs and Gecarcinidae access to bait. However, the following factors complicate the use of bait-stations on land crab islands: 1) *Birgus latro* can dismantle just about any easily manufactured, easily transported bait station. 2) Bait-stations with complex crab exclusion devices or structures also are at high risk of excluding individuals of the targeted species. 3) Different target species show varying ability to access bait-stations designed to exclude land crabs. For example, a bait-station raised 30 cm off the ground to deter hermit crab piling, will be easily accessed by *Rattus rattus*, though some *Mus musculus* might be excluded.

Following is a list of recommendations for further investigation of this topic:

1. Summarize all available information on bait-station designs used in eradication projects on land crab islands

2. Coordinate active eradication project managers in the development of “best practice” bait-station designs for all common combinations of land crab genera

and target species, e.g., *Coenobita* and *M. musculus*, *Birgus*, *Coenobita*, and *R. rattus*, etc.

3. Field test best practice bait station designs within the context of a biomarker study to assess the accessibility factor for targeted species.

BAIT MASK FOR LAND CRABS

The development or discovery of a scent that simultaneously repels land crabs while attracting, or at least not detracting rats seems like a simple solution to the complex land crab problem. However, several complicating factors need to be considered when pursuing this topic. 1) The scent, or bait mask cannot increase the risk of toxin exposure for other non-target species. 2) In multi land crab species environments, the bait mask needs to be effective for all land crab species. Even though both are opportunistic omnivores, Brachyurans and Coenobitids utilize different sensory mechanisms to "smell" or detect food items, which could mean a difference in tolerance of or repulsion to the bait mask. The first known bait mask study was conducted in 2007 on Wake Atoll, where hermit crabs (*Coenobita perlatus*) showed consistent disinterest in anise flavored wax plugs (*C. perlatus* readily consume peanut butter flavored wax). The study was not taken to the next level as rat attraction to anise was not investigated.

Following is a list of recommendations for further investigation of this topic:

1. Search available literature for mention of land crab aversion to certain compounds.

2. Conduct laboratory trials with both land crabs and target alien species to determine the respective deterrence and attraction of compounds identified in the literature search, or novel compounds if the literature search is fruitless.

3. Trial promising compounds within the context of a biomarker study.

LAND CRAB SEASONALITY

Coordinating eradication efforts with land crab breeding cycles will likely facilitate mitigation of the land crab problem; however, in most cases this practice will not be a stand-alone solution. With exception of one obscure land crab species that deposits eggs in brackish to fresh water pools (Burggren and McMahon 1988) land crabs maintain their connection to the marine environment through a marine (and sometimes pelagic) larval stage. Gravid females migrate to the land's edge to release their eggs into the ocean; males clamber after the females to fertilize the release eggs. Where such migrations are predictable, we can theoretically decrease land crab interference with eradication actions by baiting on or just before a mass migration. In general, land crab breeding is cyclical, and corresponds with spring tides. However, there is variation across land crab genera in the degree to which they adhere to this principle. For example, the Gecarcinidae at Palmyra deposit eggs in the ocean around spring tide events

(Wegmann, personal observation), but they do not do so en-mass. Also, gravid females actively forage (also observed) so it would be hard to predict how much of the population would be distracted by reproductive tasks at certain times, and for what amount of time. Thus it would be hard to base an eradication program on this type of phenomenon. The story is a bit different on Christmas Island (Indian ocean) where millions of Brachyuran crabs (*Gecarcoidea*) mass migrate annually to the shoreline to deposit and fertilize eggs in the ocean. This event leads to a subsequent (several months later) mass migration to land by newly molted juvenile crabs. The Christmas Island scenario could lend itself well to eradication planning. Another factor to consider is that en-massed breeding and juvenile crabs might be easy prey for targeted alien species. It is undesirable to implement a bait-based eradication project when natural food sources are superabundant. Following is a list of recommendations for further investigation of this topic:

1. Summarize the available literature on land crab migration patterns to determine which species in which regions engage in mass breeding migrations

2. Conduct bait consumption studies in conjunction with mass migration events to determine if such phenomena correlate with a decrease in overall bait consumption and an increase probability of exposing all individuals of the targeted species to the applied bait. Again, operating within the context of a biomarker study will enhance the ability to detect if this method has any effect on target species exposure to bait.

NON-TARGET SPECIES RISK

Non-target species risk did not receive as much attention in the accounts as the topics mentioned above; however, it is a serious enough issue to warrant mention here. By way of documented predator-prey relationships, land crabs provide a toxin pathway to an array of non-target species, including birds and humans, though the severity and duration of this risk has not been thoroughly studied. Non-target mitigation measures must be in place well in advance of an active bait application. When operating on islands with land crab consuming human populations, the public must be educated about the toxin exposure risk linked to consuming land prior to implementation, preferably years beforehand.

Following is a list of recommendations for further investigation of this topic:

1. Compile available information on commonly used eradication toxicant residue levels in land crabs and construct a risk assessment model for non-target species at risk of exposure through land crab consumption.

2. Use the compendium to inform non-target risk mitigation efforts prior to and during eradications on land crab islands.

CONCILIANCE

The primary goal of this document is to initiate a collaborative investigation of methods and tools that will promote efficient, effecting conservation actions on tropical islands. For all of the topics discussed above, the underlying imperative is cooperation between those engaged in alien vertebrate eradications on land crab islands. Solutions to the land crab problem will only arise from a collective effort to share, compare, and constructively question the available information; future studies should employ standardized methods so that study replication, and subsequent confidence in results and practices can be achieved at a regional or even global level.

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Appendix: Qualitative data mined from emailed responses to the land crab interference with eradication projects query. The comments, questions and suggestions listed below are from the following individuals: (AC) Andy Cox – NZ Dept. of Conservation; (AW) Alex Wegmann – Island Conservation; (BB) Brian Bell – Wildlife Management International Ltd; (MT) Mike Thorsen – NZ Dept. of Conservation; (PM) Pete McClelland – NZ Dept. of Conservation; (MP) Michel Pascal - INRA - Equipe Gestion des Populations Invasives; (RP) Ray Pierce – Eco Oceania Ltd; (SB^1) Souad Boudjelas – Pacific Invasives Initiative; (SB^2) Stacey Buckelew – Island Conservation; (SC) Steve Cranwell – Birdlife International

Bait application rate

Comments

We don't know how much bait is required for just rats, let alone rats and crabs (AC).

Early eradications in NZ employed high applications rates; such rates have been brought down with continued eradication success; however, we do not know what the lower limit application rate is (AC).

What is the necessary bait density and baiting regime (number of applications, delivery system) to achieve eradication on tropical islands with crab related bait consumption (MT)?

Application rate must be driven by two factors: enough bait to kill every rat, and guaranteed access to bait for every rat (AC).

Gaps in bait coverage are a more likely reason for failure than actually volume of bait applied (AC).

Requirement for enough bait to remain at some density for three nights after the drop originated with 1080 possum eradication trial and error process. This has been adopted by the rat eradication group, but never fully tested to see if only one night, or two nights would be sufficient. Island Conservation took the "three nights" rule one step further by applying bait at a rate that ensures every rat access for all three nights [at Palmyra] (AC).

Advocate a conservative approach to eradications; if you can do something to reduce the risk of failure, do it (AC).

We need to discover the linear relationship between necessary application rate and *Coenobita* [Land crab] density (RP).

Questions and suggestions for future research

How much bait do we need to apply to ensure that every rat has access to a lethal dose (AC)?

High application rates (e.g. 90 kg/ha, Palmyra) are generally unaffordable and/or logistically impossible for most tropical Pacific islands; it is necessary to take on more risk (reduced application rate) to allow more eradications (AC).

We need more emphasis on figuring out a way to quantify effective, efficient bait application rates in the presence of land crabs (SB^2).

Bait deterrent

Comments

At Palmyra, full-factorial bait preference trials were conducted with 2 *Cardisoma* sp. and 2 *Coenobita* sp., and 4 commercially available baits – The Ramik product was avoided by all crabs (SB^2).

At Wake Atoll, 36 trials found that *Coenobita perlatus* prefers coconut, PI-25 wet, Ramik kibble to anise scented wax plugs; Coconut was the most frequently chosen bait, then Ramik 2 g kibble, then Bell PI-25 wet formulation (AW).

Development of bait that deters land crabs and is simultaneously highly palatable to rats could drastically minimize crab interference with eradication programs and significantly reduce non-target risk (AW).

Questions and suggestions for future research

The use of a masking scent in bait as a crab deterrent warrants further investigation (SC).

Land crab bait consumption

Comments

In the Seychelles, crabs averaged between 75% and 100% bait take each night before bait was secured in bait stations (MT).

In the Phoenix Islands, *Coenobita* can consume 10g bait/crab/night, and consumed 80%-90% of available bait per night with an average consumption rate of 40 kg/ha. *Coenobita* also "smother" pellets, which could further prevent rats from accessing bait (MT).

At Palmyra, five land crab species are involved in bait take: *B. latro*, *Cardisoma carnifex, Cardisoma rotundum*, *Coenobita perlatus* and *Coenobita brevimanus* (SB^2).

At Palmyra, *Cardisoma* sp. are believed to be responsible for most of the bait consumption because of their large size and food caching behavior (SB^2).

Crab related bait take might have led to failure of first eradication attempt on Vahanga (SB^1).

Anomuran (Coenobitidae) and Brachyuran (Gecarcinidae) crabs are primarily responsible for bait take (AW).

All Brachyuran crabs burrow to some extent - bait hoarding may occur in burrows (AW).

Rats are competitively dominant in acquiring broadcast bait pellets; however the sheer number of land crabs (3:1 crabs to rats at Palmyra) weakens this advantage (AW).

Questions and suggestions for future research

We need a common methodology for determining bait removal rates by crabs (SC).

Land crab and rat bait consumption

Questions and suggestions for future research

We need to develop a repeatable methodology for determining bait application rate based on crab and rat density (SC).

Land crab behavior

Comments

Most land crabs are crepuscular or nocturnal to avoid desiccation; however they will push the desiccation envelope to access readily available food, e.g. bait (AW).

Griffiths et al. found no relationship between crab numbers and proximity to vegetation or water suggesting that observed daytime preference for particular habitats dissolves when crabs are more active at night. Crab movement data from Palmyra supports this notion (AW).

Land crab density

Comments

Coenobita perlatus density can be as high as 5000/ha in the Phoenix Islands (MT).

There is no accepted method of quantifying crab abundance that is meaningful to managers (RP).

The density and proportion of different land crab species varies from island to island (AC).

Gecarcinus ruricola abundance increased after rat eradication (MP).

At Palmyra, a method to index crab density using random fixed width transects was developed (SB^2).

Burrowing crabs (*Gecarcoidea* & *Cardisoma*) can be more than 1/per burrow and often retreat to burrows 30-50m in front of someone walking through the forest – this makes it difficult to obtain a solid estimate of crab density for burrowing crabs, and is a good reason to stick with an index as a comparable measure (AW).

Land crab abundance appears to be variable across islands and between species (SC).

Questions and suggestions for future research

We need to determine a cost-effective way of measuring crab density and standardize the sampling method: day vs. night, transect vs. plot (RP).

We need to determine the seasonality of crab populations (RP).

None of the successful eradication projects have employed a repeatable land crab density survey technique; this is greatly needed (AC).

We need to define the extent of bait removal by crabs (SC).

We need to establish standardized way of indexing crab densities (PM).

The best technique for measuring crab density is mark-recapture or counts on grids (MT).

Land crabs and bait-stations

Comments

"Crab-proof" bait-stations are likely excluding rats as well as crabs (PM).

On large islands, a bait-station approach involves impractical labor and time investments; 5000 bait-stations would be needed for 780 ha Wake Atoll (PM).

Bait-stations exclude *Cardisoma*, but *Coenobitas* will pile in front of the entrance to gain access to bait (MT).

Questions and suggestions for future research

Are bait-stations the only practical solution to the crab-bait problem (SC)?

There is a definite need for more biomarker trials with bait-stations to determine the rat exclusion factor (PM).

For small islands, is there a bait-station design that will exclude land crabs at high densities (MT)?

How do rodents react to new objects in their environment, e.g. bait-stations? How long does the neophobia last? Anecdotal evidence supports 30-40 days, is this correct (MT)?

Land crabs as secondary toxin pathway to rats

Comments

R. rattus commonly preys on *Coenobita*, and juvenile Brachyurans and *Birgus* (AW).

Eradications on crabby islands

Comments

There have been few successful eradications on land crab islands (AC).

Inhabited Islands

Comments

Inhabited islands are a problem because you cannot always get total agreement and commitment from all (BB).

Non-target issues

Comments

Land crabs are a pathway for toxins to reach non-target species including shorebirds, rails, kingfishers, insectivores, pigs, dogs, and humans (AW).

We are ignorant of non-target mortality risk, especially for the Bristle-thighed Curlew (RP).

All projects need to monitor and mitigate for non-target risk (RP).

Where are crabs a problem

Comments

Crabs are not a problem inland on large islands, such as Mauritius (MT).

Crabs are mostly a problem in wetland areas and coastal habitats (MT).