*Phelsuma* **13**; 44-54

# The impact of rodent eradication on the larger invertebrates of Fregate island, Seychelles.

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**Abstract:** Island populations are often regarded as being threatened by introductions of alien rodents. In 2001 brown rats (*Rattus norvegicus*) were eradicated from Fregate island, Seychelles. A study of population sizes of the larger invertebrate species potentially at risk from rat predation was carried out in 1999. This covered the giant tenebrionid beetle (*Pulposipes herculeanus*), Seychelles giant scorpion (*Chiromachus ochropus*), Fregate enid snail (*Pachnodus fregatensis*) and the Fregate streptaxid snail (*Conturbatia crenata*). Population estimates were repeated in 2002, a year after the rat eradication had been completed. Comparison of these estimates indicates that there has been little change in beetle and scorpions populations, both of which are considered to be Vulnerable on the basis of restricted ranges. The snails have declined significantly. The snail population declines are suggested to be a result of the broadcast use of the molluscicidal rodent poison Brodifacoum during the rat eradication. *P. fregatensis* is regarded as Endangered as a result of this population decline and *C. crenata* may be extinct.

**Keywords:** *Chiromachus,* conservation, *Pachnodus, Polposipes,* rodent eradication

The impact of introduced mammals on the ecology of islands has been widely reported in the context of the population declines of vertebrates, especially birds. Comparatively little information is available concerning invertebrates. Exceptions to this include accounts of the declines of weta crickets (*Hemideina* and *Gymnoplectron* species; Brown 1997; Green 2002) on the off-shore islands of New Zealand and the *Partula* snails in Polynesia (Cowie 1992). In 1995 brown rats (*Rattus norvegicus*) colonised Fregate island, Seychelles and the early stages of the process of population establishment recorded (Thorsen *et al*. 2000). Over the past 20 years there have been numerous alien mammal eradication projects carried out on islands around the world, these have been reported to result in dramatic recoveries of habitat and threatened vertebrates but little consideration has been given to the impacts of rodent removal on invertebrates (Eason & Spurr 1995), exceptions are the documentation of population increases in tree wetas (*Hemideina crassidens*) following rat eradication (Brown 1997). Invertebrates have generally been assumed to be immune to poisoning by supposedly mammal specific poisons (Shirer, 1992). Residues of Brodifacoum poisons have been detected in arthropods (Morgan *et al*. 1996; Ogilvie *et al*. 1997; Pain *et al*. 2000) and other invertebrates, including gastropods (Morgan *et al*. 1996). The effect of Brodifacoum on molluscs was investigated in more detail by Gerlach & Florens (2000a&b), indicating that some species are highly vulnerable to poisoning, and concern was raised over the potential impacts on molluscs on Fregate island.

Fregate island is the seventh largest island in the Seychelles group (219

hectares) and the ninth highest (125m above sea level). Given the depth of the marine channel between Fregate and the other granitic islands it has probably been isolated from the rest of the Seychelles islands for the last 12,000 years. Fregate has retained an unusual fauna with significant populations of taxa now rare on the other Seychelles islands (e.g. the giant scorpion *Chiromachus ochropus* Koch, 1838), species now extinct elsewhere (e.g. giant tenebrionid beetle *Polposipes herculeanus* Solier, 1848) and distinctive endemic species (e.g. the endemic snail *Conturbatia crenata* Gerlach, 2001). All of these species persist on what is at first sight one of the most disturbed and un-natural of the Seychelles islands. By the 1970s Fregate was recognised as supporting an important fauna even though only the conspicuous species such as the Seychelles magpie robin *Copsychus seychellarum*, Seychelles fody *Foudia seychellarum* and giant tenebrionid beetle were mentioned in popular publications (Lionnet 1971). Until the late 1990s research on the island was been limited to studies of the birds (Crook 1961; Komdeur 1996; Gretton 1990-2; Burger & Lawrence 2001) and reptiles (Rendahl 1939; Gardner 1987) and small collections of invertebrates (Gebien 1922; Hirst 1911; Benoit 1978) and plants (Robertson 1987).

The first description of Fregate in 1787 gives an impression of scrub habitat and low trees (Fauvel 1909), resembling islands such as Aride which were, and are still, covered in *Pisonia granids* woodland. The scrubby nature of the habitat persisted until the late 1800s at least (Pike 1873). Pike mentioned a more developed woodland type on the plateau. The presence of an endemic woodland species of snail (*Conturbatia crenata*) suggests that this was a significant, if localised, habitat in the past (Gerlach 2002).

During the early 1900s the island was settled and cleared for coconut (*Cocos nucifera*) plantation with vanilla (*Vanilla planifolia*) established on stakes of *Pterocarpus indicus*. These stakes subsequently grew and now form the main woodland areas on the island, with *Pterocarpus* woodland replacing the natural forest habitat. To some animal species the new *Pterocarpus* woodland may have represented an improvement on the very open, dry *Pisonia* woodland of the past. The more structurally complex *Pterocarpus* woodland, its fissured bark and its high input of dead wood may have allowed the native fauna to survive despite the loss of the natural habitat. This fauna may be threatened by introduced animals: the Indian mynah (*Acridotheres tristis*) is reported to be a competitor and predator of the magpie robin (McCulloch 1996), house mice (*Mus musculus*) have been present and abundant on the island for many years, cats (*Felis cattus*) were present from the late 1950s but were eradicated in 1982 (Todd 1982). Brown rats (*Rattus norvegicus*) colonised the island in 1995, apparently in cargo for the island's plantation (McCulloch 1996). There are no quantified published data on the impacts of these species and their significance cannot be assessed at present. Alien species also include a wide variety of plants as well as animals; *Chrysobalanus icaco* is an aggressively invasive species in exposed areas and *Alstonia macrophylla* is a recent but already significant invader.

The invasion by rats was seen as a potential threat to the endemic invertebrate fauna and *ex situ* captive breeding was initiated by the Nature Protection Trust of Seychelles (NPTS) and the Zoological Society of London (ZSL) to safeguard the

survival of the most vulnerable species until such time as the rats had been eradicated (Anon. 1996; Ferguson & Pearce-Kelly 2005). Giant tenebrionid beetles, enid snails, giant millipedes and giant scorpions were collected and transported to ZSL in 1996 (Lucking & Lucking 1997) and 1999 (Gerlach 1999b).

The giant tenebrionid beetle is the best known of Fregate's invertebrates. Historically it was present in the Mascarenes and probably widespread in Seychelles but declined as a result of habitat destruction (Gerlach *et al*. 1997). Although natural habitats persisted on Fregate in the 19th century the beetle remained overlooked and presumably occurred at low densities, by 1905 it was more abundant or conspicuous and significant numbers were collected (Gebien 1922). Since then it has remained an abundant part of the island's fauna. The presence of the Fregate enid snail *Pachnodus fregatensis* Van Mol & Coppos, 1980 was first reported in 1972 (as *P. ornatus*) (Lionnet 1972). It was not described as an endemic species until 1980, based on specimens collected in 1972 on banana trees along the Rivière Bambou (Van Mol & Coppois 1980). In 1989 it was found to be locally common in agricultural areas of the plateau but despite searching only a single individual could be found in woodland (pers. obs.). The giant scorpion (*Chiromachus ochropus*) is known from four islands in Seychelles and the Mascarenes (where it is now extinct); a record from Zanzibar is believed to be an error (Gerlach 1999a). Fregate is the only island where it is abundant. There are no data on historical abundance on the island Fregate; it was first recorded there in 1838 (Koch 1838) and has been recorded regularly since then. The Fregate streptaxid snail (*Conturbatia crenata*) snail is known from a single specimen found in *Pterocarpus* woodland in 1999. It is Fregate's only endemic genus and represents an interesting biogeographical anomaly (Gerlach 2002). This status makes it the most important Fregate species for biodiversity conservation.

The location of rats in 1995 prompted an eradication attempt a few months after the first rats were seen. The extensive use of traps caught many rats but was suspended when birds were also caught. The use of anti-coagulant poisons was also tried at the same time but the poisoning of a magpie robin led to the suspension of this method. Eradication was changed to a policy of containment using live traps, this was also unsuccessful and rats rapidly spread across the island (Thorsen *et al*. 2000). In 2000 an eradication project was undertaken by the Seychelles Government's Division of Environment using broadcast poisoning the anti-coagulant Brodifacoum (Merton *et al.* 2001). Poisoning controls and eradication of rats have been tried elsewhere without noted losses of reptiles or invertebrates, however, there are no published studies specifically addressing the impact on these animal groups. Anecdotal reports of a Brodifacoum poisoning programme in Mauritius report a decline in numbers of native molluscs and studies of the Seychelles fauna indicated that poisoning represented a risk to *Pachnodus* snails (Gerlach & Florens 2000a&b).

A visit was made to Fregate in 2002 to assess the impacts of the rat eradication on the invertebrate fauna. The results of this study are reported below and compared to data collected by the author in 1999 (prior to rat eradication). Giant millipedes were studied as part of a wider study reported in Gerlach *et al*. (2005).

**Methods**

In order to determine whether or not habitat change was an influence on any invertebrate populations vegetation composition and structure studies carried out in 1999 were repeated in 2002. Habitats can be categorised as *Pterocarpus* woodland (*P. indicus* dominated), coastal woodland (mixed native coastal species), mixed woodland (*P. indicus* and *Anacardium occidentale* abundant), scrub (*Chrysobalanus icaco* and *Panicum maximum*), coconut plantation, agricultural (including open grass) and settlement (Fig. 1). All of these represent un-natural habitats created through agricultural or conservation plantation, they are therefore in habitat blocks and are easily distinguished in the field. In each habitat area the number of trees over 2m tall were recorded and identified to species in 10 haphazardly positioned quadrats of 5x5m.

Population density estimates were made for each of the invertebrate species previously suggested to be of conservation concern (Gerlach 1997). Tenebrionid beetles were studied using a survey method used on the island since 1993 (McCulloch unpublished data; Lucking & Lucking 1997). 20 trees were haphazardly selected in each habitat survey quadrat and the number of beetles visible to 5m above ground counted to give a measure of abundance per tree (with a record of tree species). This method of surveying tenebrionid beetles is strongly influenced by the vertical movement of beetles on the trees. In order to provide an indication of possible changes in the vertical distribution of beetles in the two surveys one tree in each quadrat was observed with binoculars for 30 minutes. The location of each beetle was recorded in visually estimated 5m bands. Snails (*Pachnodus fregatensis* and *Conturbatia crenata*) and giant scorpions were also counted by searching under all moveable rocks and logs in the quadrats. *C. crenata* occurred at extremely low densities; in order to obtain statistically meaningful density estimates an additional 100m$^2$ were searched near each quadrat, giving a total search area of 125m$^2$ in each site.

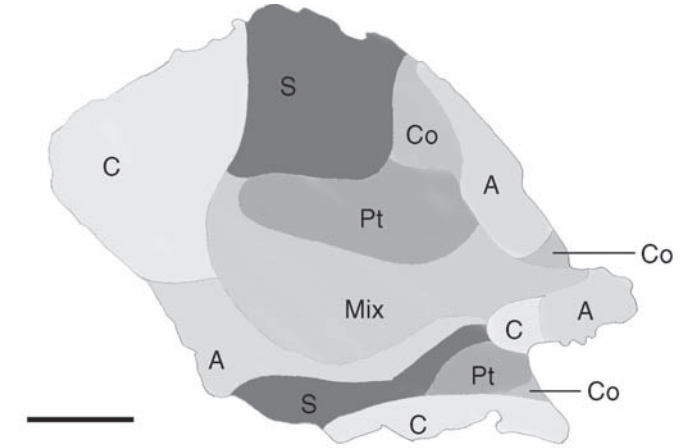


**Fig. 1** Habitats of Fregate island in 1999. A = agricultural and settlement; C = coconut plantation; Co = coastal; Mix = mixed; Pt = *Pterocarpus indicus*; S = scrub. Scale bar 300m

Only the scorpions show sexual dimorphism; Krapelin (1896) recorded that males had relatively elongate claws (length:width=1:0.6) compared to females (length: width=1/0.8) and had tails longer than their abdomens (female tails being shorter); in the present study adults were sexed to investigate differences in sex ratios. Snails were divided into age classes: hatchling (<2 whorls), juvenile (<6 whorls), subadult (full sized but without a developed shell lip) and adult (with a fully developed lip).

**Results**

The composition of these habitats and their approximate areas (estimated from aerial photographs and data in Komdeur 1996) are shown in Table 1. No significant habitat change had occurred other than an increase in tree density and area of coastal woodland, at the expense of agricultural areas and the increase of coastal tree species in scrub and mixed woodland. The areas of habitat changed significantly over this time, with coconut plantations being replaced by coastal woodland.

The abundance of the invertebrate species in different habitats is summarised in Fig. 2 and 3. Statistically significant changes (as indicated by paired-sample t tests) are highlighted. The vertical distribution of beetles showed a peak in numbers below 10m, there was not notable change in the two survey periods. For *Pachnodus fregatensis* snails the population structure in September 1999 showed an adult bias (67%) with relatively few subadults (22%) and juveniles (11%). This pattern is similar to that seen in other *Pachnodus* species (Gerlach 2001b). A higher proportion of juveniles and hatchlings may be detectable in the main breeding season which would be expected to coincide with periods of high rainfall (November-March). In October 2002 adults could not be located and the population was subadult biased (67%). *Conturbatia crenata* was found as a single individual in 1999 in a *Pterocarpus* woodland quadrat. This gives a maximum population density of 400 per hectare in 1999. Despite careful searching in 2002 this species could not be located.

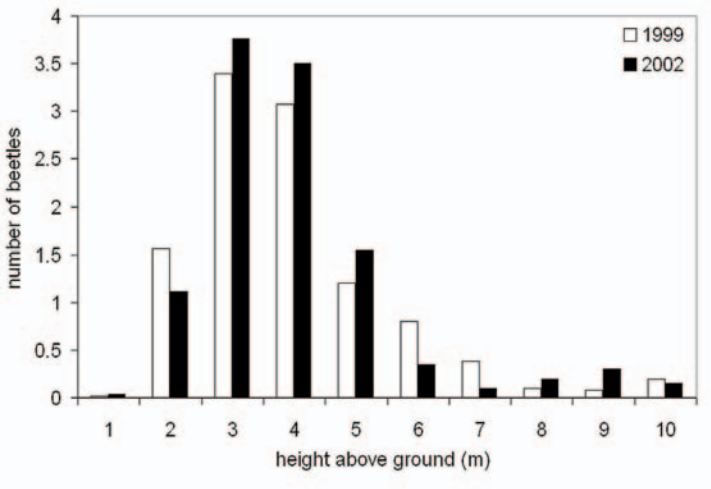


**Fig. 2.** Vertical distribution of *Polposipes herculeanus* beetles in 1999 and 2002

**Table 1.** Habitat areas and tree densities on Fregate.

| Year | Habitat | Density of trees (per hectare) | | | | | | | | Area (ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Artocarpus* | *Pterocarpus* | *Cocos* | Cinnamomum | *Ficus* | Alstonia | coastal spp. | other | |
| 1999 | *Pterocarpus* | | 1,700 | 100 | 150 | 100 | | | | 13 |
| | coastal | | | | | | | 3,200 | 100 | 8 |
| | mixed | 100 | | | 1,100 | 267 | 100 | 100 | | 10 |
| | Scrub | | | | 400 | 100 | 1,000 | | | 60 |
| | Coconut | | | 4,000 | | | | | | 92 |
| | Agriculture | | | | 100 | 100 | | | 200 | 15 |
| | Settlement | | | | | 100 | | | 300 | 5 |
| 2002 | *Pterocarpus* | | 1600 | | *133* | | | 67 | 67 | 13 |
| | coastal | 267 | | 133 | | | | 10,000 | 333 | 14 |
| | mixed | | | | 1,200 | 300 | 200 | 400 | 300 | 10 |
| | Scrub | | | | 400 | 100 | 2,000 | 400 | 100 | 54 |
| | Coconut | | | 4,100 | | | | 2,800 | | 90 |
| | Agricultural | | | | | | | 100 | 100 | 15 |
| | Settlement | | | | | | | | 400 | 5 |

**Table 2** IUCN status assessments (criteria from IUCN 2001)

| *Species* | *Population* **1999** | **2002** | **change** | **Occupancy area (km²)** | **Status** |
|---|---|---|---|---|---|
| *Pulposipes herculeanus* | 57,060±9,038 | 50,390±3,288 | -12% | 2.0 | VU D2 |
| *Chiromachus ochropus* | 16,925±4,554 | 17,689±7,025 | -20% | 2.0 (Fregate), 9.0 (all) | VU D2 |
| *Pachnodus fregatensis* | 57,910±5,407 | 7,730±880 | -87% | 2.0 | **EN A2a** |
| *Conturbatia crenata* | 5,200±125 | Extinct ? | ->80% | 0.1 | CR A2a |

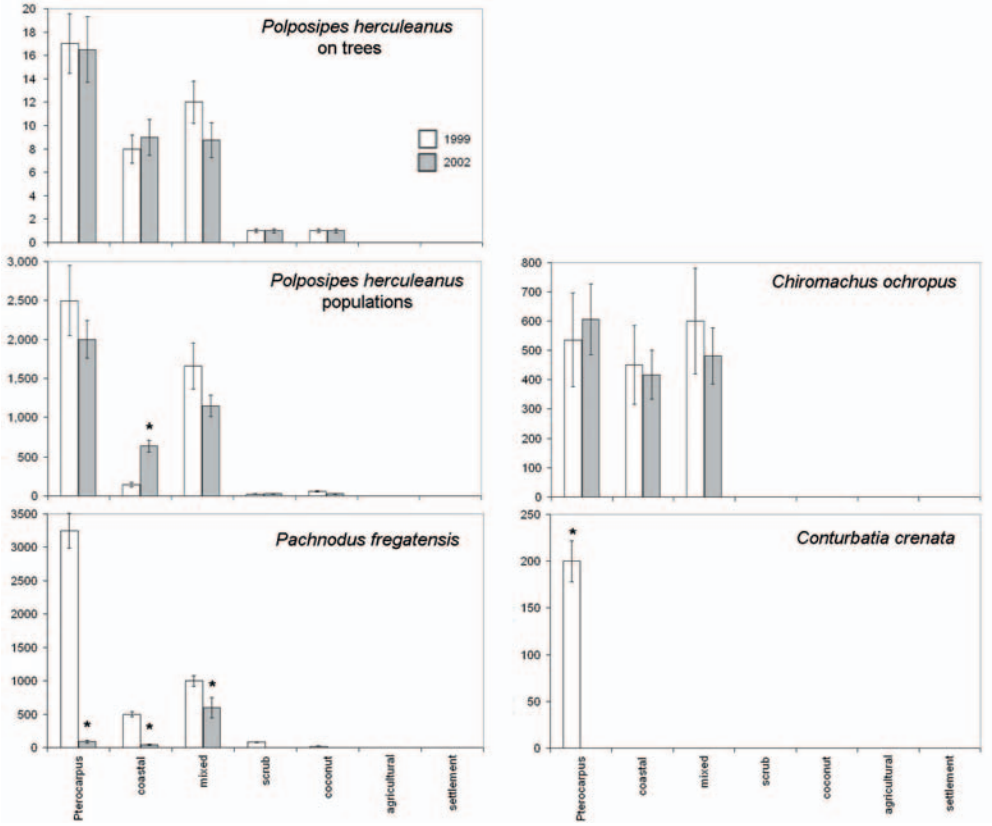


**Fig. 3.** Population density changes of studied invertebrates in 1999 and 2002. Significant differences ($P<0.05$) marked with asterisks. Vertical axis is numbers per hectare except for *Polposipes herculeanus* on trees where it is numbers per 20 trees.

The giant scorpion population in 1999 was strongly female biased (1:4.5 n=11 adults). The adult to juvenile ratio varied locally, disturbed areas being adult biased (9:1 n=20) compared to undisturbed areas (1:3.5 n=20). In 2002 the female bias was still present (1:9 n=10), the adult to juvenile ratio was 1:2.5 (n=14) in the undisturbed area and 1:3.8 in the previously disturbed area (n=24).

**Discussion**

The invertebrate populations studied here showed no overall pattern of population change. In the case of the giant tenebrionid beetle there is little change in overall population although increases in population density occurred in coastal woodland as this has matured and improved as a habitat. As a slow moving, flightless

and apparently defenceless beetle this species was feared to be at risk from rat predation and there were reports of rat-chewed elytra (Murray & Nicoll 1999), although this has not been verified. The threat posed by the rats was investigated by beetle population monitoring by BirdLife International staff on Fregate from 1996 (Lucking & Lucking 1997). In 6 sites in the north-eastern half of the island all beetles visible on 20 trees were recorded. In 1998 one of these sites was lost to harbour development (Murray & Nicoll 1998); the remaining 5 sites continue to be monitored. The 1996-7 data showed considerable variation and indicate a strong seasonal effect of beetle activity which complicates data interpretation. Subsequent data have not been made available except in a summarised form (Murray & Nicoll 1999). This summary was used to demonstrate a catastrophic population decline but is difficult to interpret due to observer differences and statistical problems (J. Millet pers. comm.), a major component of the variation reported appears to be due to seasonality (Lucking & Lucking 1997). The reported decline has been presented as a linear regression (Murray & Nicoll 1998) showing a significant decrease in the number of beetles recorded ($y=214.04-3.3487x$; $R^2=0.388$; $P<0.05$). This analysis fails to take into account the change in survey areas following the development activity on Fregate. If the disturbed sampling areas are excluded from the 1996-8 data the corrected regression fails to provide any evidence of significant overall population decline ($y=34.067-0.4091x$; $R^2 = 0.195$; $P>0.05$). Increases in the beetle population size in 2001, within 12 months of rat eradication has been reported (Hill 2001). Although this is only a short time after rat eradication, as the tenebrionid beetle larvae take 6-8.5 months to mature and generation time is 7-10 months (Ferguson & Pearce-Kelly 2005) a sustained increase from mid 2001 is possible, although not apparent in the 2002 monitoring data. Thus the impact of rat presence and eradication remains equivocal for this species. The continued improvement in natural habitat on Fregate through ongoing replanting should enable populations of this and other invertebrates to recover or to continue expanding. It is believed that the giant tenebrionid beetle was once present in coastal habitats of most of the Seychelles islands and it could be reintroduced to some of its former range. As definite records are lacking, reintroduction would only be appropriate to areas with suitable habitat and where it can be demonstrated that a reintroduction would not have an adverse effect on any existing indigenous species, such criteria are met for the islands of Aride and Cousine as these have abundant soft dead wood from coastal woodlands and studies of dead-wood inhabiting invertebrates indicate the absence of large wood boring beetles with the exception of widespread elaterid beetles (Kelly & Samways 2001; Meegan & Gerlach 2000; Phillips 2001).

No significant change is apparent in the giant scorpion population overall. The area of *Pterocarpus* woodland disturbed (by relatively frequent rock movement within the past year) in the late 1990s was adult biased in 1999 but in 2002 was not notably different from undisturbed habitat. This suggests that juveniles are vulnerable to disturbance, possibly by increasing the risk of predation. Rat predation on the giant scorpion has been reported (K. Murray & M. Nicoll pers. comm.) although this has not been substantiated. Fregate supports the only remaining significant population of *C. ochropus* scorpions, the causes of declines in this species on other islands remain to

be identified and research into the ecology of this species continues.

The Fregate enid snail has suffered a major decline in population, falling to 13% of the 1999 population by 2002. This occurred in all habitats although not evenly; in *Pterocarpus* woodland populations were reduced to 3%, 14% in coastal woodland and 60% in mixed woodland. The species was very scarce and localised in 1988 (pers. obs.) but was abundant in 1996 (R. Lucking pers. comm.) and in 1999 it was found to be highly abundant in woodland areas. The apparent population increase between 1988 and the mid-1990s corresponds to a major ecological change in the removal of free-range chickens and pigs (McCulloch 1996), both of which would have acted as major predators of the snails. No evidence of predation by rats was observed in 1999 and none has been reported. *Conturbatia crenata* also appears to have declined substantially since 1999. As only a single specimen was be located in 1999 any comparisons are necessarily limited, but the failure to locate this species in 2002 despite intensive searching suggests that the species may be extinct or at very reduced population levels. The rat eradication programme in 2000 resulted in the dispersal 35kg/ha of Brodifacoum bait (Merton *et al.* 2001). Gerlach & Florens (2000a&b) demonstrated that Brodifacoum is highly toxic to snails, a dosage of 0.002mg was sufficient to kill *Pachnodus silhouettanus* in 4 days, higher dosages resulting in death within 12 hours; indicating that Brodifacoum is highly toxic to snails. *C. crenata* is a carrion feeder (Gerlach 2002) and this would make it highly vulnerable to indirect poisoning following consumption of other poisoned snails. The broadcasting of Brodifacoum is probably the main cause of the population decline in *P. fregatensis* and the possible extinction of *C. crenata*.

The changes in populations recorded here are due to two main factors; habitat change and direct poisoning. Habitat change has been significant between 1999 and 2002. The replacement of the original dry habitats by *Pterocarpus* woodland may have allowed population increases in species such as the giant tenebrionid beetle and the rapid habitat restoration carried out in the last 5 years is resulting in further habitat improvements. This restored habitat is a mixture of naturally regenerating *Pisonia grandis* woodland and planted areas dominated by *Terminalia catappa*, *Thespesia populnea, Heritiera littoralis* and *Ochrosia oppositifolia*. The natural distribution of habitat can only be guessed at and the composition of the original coastal woodland is unknown. Even following habitat restoration most invertebrate species will remain at risk of extinction due to their restricted ranges (most can be considered Vulnerable or Endangered under IUCN Red List criteria - Table 2).

The lack of any apparent population increases in supposedly rat-vulnerable invertebrates since the rat eradication project may indicate that rat predation was not a significant cause of mortality in 1995-2000. The 1995 invasion was reported to be the first presence of rats on the island, however, there is evidence to the contrary. In 1962 it was reported that "war has been waged on the cats and rats on Frigate by both the Department of Agriculture and the owner, who is anxious to preserve his island's heritage" (Dawson 1965). In February 1985 a rat was observed in a hotel room, coinciding with a rat eradication campaign using the anti-coagulant Warfarin. On the basis of these reports it would appear that rats were present from the 1960s, either sporadically or at low levels, possibly controlled by cats. Following eradication of

cats in 1982 (Todd 1982), rat numbers may have increased to a level where they were noticed around the hotel, prompting eradication. The population present in 1985 appears to have been successfully eradicated as no rats were recorded for the next 10 years.. In the context of this possible coexistence of the fauna with sporadic or low-density rat populations it is worth noting that although the Seychelles islands do not naturally have mammalian predators they are not naturally predator-free; there are significant populations of predatory molluscs (Gerlach & Bruggen 1999), reptiles and crabs. The endemic fauna has evolved in the context of these predators and anti-predator defences are apparent in many species, such as the high reproductive potential of *Pachnodus* snails (Gerlach 2001b) and birds (Gerlach 2001a).

The variable patterns of response to the eradication of rats on Fregate island indicates that eradication programmes involving the use of poisons need to take into consideration the potential impacts of the species present in the target areas. Conservation measures need to distinguish between the requirements of different animal phyla and resist the temptation to consider 'invertebrates' as a single group with responses that can be extrapolated from data on a narrow range of arthropods alone.

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