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Efficiency of a new reverse-bait trigger snap trap for invasive rats and a new standardised abundance index

Jörn Theuerkauf[1,*], Sophie Rouys[2], Hervé Jourdan[3] & Roman Gula[1]

[1)] *Museum and Institute of Zoology, Polish Academy of Sciences, Wilcza 64, PL-00679, Warsaw, Poland (*corresponding author's e-mail: jtheuer@miiz.eu)*
[2)] *Conservation Research New Caledonia, BP 2549, 98846 Nouméa, New Caledonia*
[3)] *IRD, UMR CBGP (INRA/IRD/Cirad/Montpellier SupAgro), Centre de Biologie et de Gestion des Populations, Institut de Recherche pour le Développement, B.P. A5, 98848 Nouméa, New Caledonia*

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We compared trapping and kill efficiency, and by-catch rate of a new reverse-bait trigger rat trap (Ka Mate) with conventional snap traps (Ezeset and Victor), and assessed methods for calculating abundance indices, over 2879 trap nights on Wallis & Futuna and New Caledonia. Ka Mate traps were most effective at killing larger (> 100 g) rats whereas Ezeset traps had the best capture rates of smaller (< 100 g) rodents. Victor mouse traps caught rodents up to 50 g, but were no more efficient than rat traps. Proportions of live captures were similar for Ka Mate and Ezeset traps, but the mass threshold for live rats in Ezeset traps was much lower than that of the Ka Mate traps. Ka Mate traps had much lower non-target by-catch rates than Ezeset traps in habitats free of land crabs. We developed a new rodent abundance index to standardise results of different trap systems.

Introduction

A variety of methods allow the control of rodent populations, of which the most common are poisoning, trapping, trap-barriers, and fertility control. Trap-barriers can be used on a small scale to protect agricultural land (dela Cruz *et al*. 2003). Fertility control allows reducing rodent numbers without killing them, but this method is still not applicable on a large scale (Jacob *et al*. 2008). At large scales, trapping and especially poisoning are used to eradicate or control alien invasive rodents on islands, where they are usually the only rodents present (e.g. Towns & Broome 2003, Lorvelec & Pascal 2005, MacKay & Russell 2005, Lock 2006, Ogden & Gilbert 2009). The use of trapping, compared with the exclusive use of poisoning, avoids the risk of primary or secondary poisoning of native species (e.g. Mendenhall & Pank 1980, Lloyd & McQueen 2000, Bowie & Ross 2006). Traps, however, put non-target fauna at risk (through by-catch) even when live traps are used (Waldien *et al*. 2004). Less powerful traps do not necessarily reduce by-catch, as some studies have reported higher bird casualties in mouse traps than in rat traps (Lane *et al*. 2010). With smaller rodent species, live traps are more efficient than kill traps

Fig. 1. Set prototype Ka Mate Medium Pro Trap (below left), Ezeset Supreme Rat Trap (upper left) and Victor Professional Mouse Trap (right).

(Pizzimenti 1979). In New Caledonia, Sherman live traps had low capture rates as compared with those of kill traps (Theuerkauf *et al*. 2007, authors' unpubl. data). Accordingly, to reduce invasive rats on a large scale, the only practical alternative to poisoning is the use of kill traps.

A number of factors, which are seldom quantified, can combine to influence capture rates during trapping. Some of the better documented influences that affect results include the relationships between rodent species (Harper & Veitch 2006, Harper & Cabrera 2010), trap density (Taylor *et al*. 2011), microhabitat, and trap layout (Cunningham *et al*. 2005). The choice of trap type is also important when designing survey methods. Numerous studies have, therefore, compared trap performance between various live traps to catch small mammals (Slade *et al*. 1993, O'Farrell *et al*. 1994, Hayes *et al*. 1996, Jacob *et al*. 2002, Anthony *et al*. 2005, Dizney *et al*. 2008), between live and lethal traps (Cockrum 1947, Sealander & James 1958, Wiener & Smith 1972, Hansson & Hoffmeyer 1973, Pizzimenti 1979, Galindo-Leal 1990), and between lethal trap designs (Edwards 1952, Smith *et al*. 1971, Perry *et al*. 1996). Few studies, however, have assessed how various trap systems influence abundance indices (Laurance 1992, Woodman *et al*. 1996, Blackwell *et al*. 2002, Ylönen *et al*. 2003).

This study set out to compare the performances of two traditional snap traps commonly used throughout the Pacific and a new design of snap trap under development. Ezeset snap traps (Cunningham & Moors 1993) and Victor snap traps (e.g. Lane *et al*. 2010) are wooden-based rat and mouse kill-traps frequently used for survey and index trapping. Both of these trap types operate in a similar way, but their trigger systems differ. The Ezeset is a baited "trigger" trap that needs baits to attract rodents, and the Victor Professional is a lured "treadle" (pressure plate) type trap that can capture rodents even without a bait (Fig. 1). With both of these systems, the trap is set off by downward pressure on the trigger or treadle, making them hair-trigger devices that can also be triggered by non-target species or falling objects. The new snap trap being developed by Ka Mate Traps Ltd. (New Zealand) has a novel "reverse-bait" trigger, designed to eliminate or significantly reduce these problems (Thomas *et al*. 2011). The radical operational differences between the trap systems make it difficult to draw comparisons based on the available methods for calculating abundance indices. These differences arise because Ka Mate traps are set off once the bait is removed, while the other traps can stay operational without bait. As such, we developed a more appropriate equation to obtain comparative results. The aim of this paper, therefore, is to: (1) re-assess methods for calculating abundance indices from trapping results, and (2) compare trapping efficiency and rate of non-target by-catch between the Ka Mate reverse-bait rat trap, the Ezeset trigger rat trap and the Victor treadle mouse trap.

Abundance indices

The simplest index to assess capture success is to consider the number of individuals caught against the number of traps set:

$$\mathrm{AI}_1 = \frac{100\sum_{i=1}^{m} n_i(\mathrm{indiv})}{\sum_{i=1}^{m} n_i(\mathrm{tr})}$$

where AI_1 is the number of individuals of a given species per 100 trap nights, n_i(indiv) the number of individuals of a given species caught during night *i*, n_i(tr) the number of traps used during night *i*, and *m* the number of trap nights.

Nelson and Clark (1973) calculated abundance indices by taking into account the number of sprung traps. This index (AI_2), which has been used as a standard in New Zealand for many years (Cunningham & Moors 1983, 1993), performs better when many traps are sprung (e.g. through rain, falling leaves or by-catch) without capturing target species (Beauvais & Buskirk 1999). A sprung trap is considered as half a trap night, whereas a set trap is counted as a full trap night regardless of whether bait is still present on the trap in the morning or not. The number of traps minus half the number of sprung traps is then considered to be the number of corrected trap nights:

$$\mathrm{AI}_2 = \frac{100\sum_{i=1}^{m} n_i(\mathrm{indiv})}{\sum_{i=1}^{m}\left[n_i(\mathrm{tr}) - \frac{n_i(\mathrm{sp\_tr})}{2}\right]}$$

where n_i(sp_tr) is the number of traps that are sprung in the morning of night *i*.

However, AI_2 does not distinguish between sprung traps with and without rats, which could lead to an index of more than 100 per 100 corrected trap nights. This can result in unrealistic indices when the trapping rate is high, for example catching 100 rats in 100 trap nights would result in an AI_2 of 200 rats per 100 corrected trap nights. To offset this bias, some papers (e.g. Jackson 1952, Choquenot & Ruscoe 2000) have used a modified version of AI_2, which rates traps that have caught target species as full traps (AI_3):

$$\mathrm{AI}_3 = \frac{100\sum_{i=1}^{m} n_i(\mathrm{indiv})}{\sum_{i=1}^{m}\left[n_i(\mathrm{tr}) - \frac{n_i(\mathrm{sp\_tr}) - n_i(\mathrm{indiv})}{2}\right]}$$

Furthermore, Simonetti (1986) noted that AI_2 does not include traps that are "unavailable" to the target species, e.g. traps with the bait removed. Simonetti (1986) therefore suggested excluding these traps entirely. However, in studies with high rates of bait removal without captures, this would lead to small sample sizes and a high variation in results. For example, one rat captured during 100 trap nights with all baits removed would lead to an index of 100 rats per 100 corrected traps nights, which is an unrealistic outcome. For this reason, we do not think that unavailable traps should be excluded from the analyses. We consider instead that, as there is little chance of rats being captured in set but baitless traps that need a bait to capture, unavailable traps should be given the same value as sprung traps, i.e. half a trap night. We, therefore, propose AI_4 as an index which factors in unavailable traps as half a trap night along with previous correction considerations (AI_3):

$$\mathrm{AI}_4 = \frac{100\sum_{i=1}^{m} n_i(\mathrm{indiv})}{\sum_{i=1}^{m}\left[n_i(\mathrm{tr}) - \frac{n_i(\mathrm{sp\_tr}) + n_i(\mathrm{un\_tr}) - n_i(\mathrm{indiv})}{2}\right]}$$

where n_i(un_tr) is the number of traps that are still set but without bait in the morning of night *i*.

Methods

Study areas

Wallis & Futuna (176–178°W, 13–14°S) are tropical islands of mixed volcanic and oceanic origins, and comprise 3 larger islands: Wallis (75 km²), Futuna (46 km²) and Alofi (18 km²). Wallis, also called Uvea, is relatively flat (max. elevation 144 m a.s.l.), surrounded by a lagoon and a barrier reef with many small islets (together 2.5 km²). Futuna and the neighboring (1.6 km apart) Alofi, situated 230 km southeast of Wallis, are higher islands (max. 524 m a.s.l) without a barrier reef. The climate is hot and humid with little variation around the mean annual temperature of 27 °C and annual rainfall of 2600–3400 mm (Beaudou and Latham 1981). Pacific rat (*Rattus exulans*), black rat (*Rattus rattus*), Norway rat (*Rattus norvegicus*) and house mouse (*Mus musculus domesticus*) are all introduced and naturalized to Wallis & Futuna (Theuerkauf *et al*. 2010). In 2007 and 2008, we caught rodents in all main habitats of the three islands: native rain forest, planted pine forest, *Dicranopteris* fernland, garden, coconut plantation and taro field (Morat & Veillon 1985). Hermit crabs (Paguroidea) are abundant in all habitats.

Mainland New Caledonia (164–167°E, 20–22°S) is a large continental island (16 000 km²) with a central mountain range (up to 1628 m) and is surrounded by a large lagoon and a barrier reef. The climate of New Caledonia is tropical oceanic with mean annual temperatures ranging from 22 °C to 24 °C and mean annual rainfall varying from under 1000 mm on the west coast to over 4000 mm in the central mountain chain (O.R.S.T.O.M. 1981). The same four invasive rodent species occur in New Caledonia (Rouys & Theuerkauf 2003) as on Wallis & Futuna. From 2001 to 2010, we worked mainly in rain forest that occurs along the island's central mountain ridge.

Traps

We compared three types of snap trap during this study: "Ezeset Supreme Rat Traps" (A.W. Stanfield & Co., Australia), "Victor Professional Mouse Trap" (Woodstream Corp., USA), and a prototype of "Ka Mate Medium Pro Traps" (Ka Mate Traps Ltd., New Zealand). The wooden based Ezeset trap is a baited trigger snap trap with a small metal, pivoting trigger that baits on top. The trap weighs 160 g when dry (about 50% heavier when wet) and measures 175 × 80 × 34 mm. The Victor mouse trap is a smaller wooden-based trap, weighing about 20 g (about 50% heavier when wet) and measuring 99 × 46 × 15 mm. It is of a more contemporary design with a large yellow plastic treadle (or pressure plate) in place of a trigger and does not necessarily require a bait or a lure.

Constructed in aluminum, the hand-made Ka Mate prototypes were heavier (215 g) than the Ezeset rat trap, but smaller (157 × 76 × 20 mm). The reverse-bait trigger is a new approach in snap-trap design. When the trap is set, solid bait (e.g. hazel nut, raw coconut) is placed beneath the trigger and held firmly in place by tension, essentially becoming a structural part of the trap (Fig. 1). Unlike top-loading trigger or treadle traps, the Ka Mate trap cannot be accidently sprung by the weight of small animals (target or non-target) or the influence of environmental disturbance (e.g. rain, snow, falling sticks or leaves) on the trigger. The Ka Mate trap prototype is the precursor of the "Ka Mate Medium Pro Trap" (a manufactured model in the final stages of development). It is a lighter version of the "Ka Mate Medium SafeTcatch Trap" (256 g), which is already commercially available (www.kamatetraps.com).

Field work

During comparative trap trials undertaken from 2007 to 2010, we caught rodents over 1479 trap nights at 12 sites on Wallis & Futuna (552 Ka Mate trap nights, 594 Ezeset, 333 Victor) and over 1400 trap nights at 14 sites in New Caledonia (730 Ka Mate, 670 Ezeset). Each trap line consisted of 25 trapping stations spaced at 25-m intervals along the sampling line established by following a compass bearing. Because external factors such as trap location, spatial arrangement, habitat and season can influence trapping success of small mammals (Weihong *et al*. 1999, Cunningham *et al*. 2005), it is common practice to compare the efficiency of different trap types by conducting paired trap trials at the same time and place. However, we knew from earlier trials (Bruce Thomas, Ka Mate Traps Ltd., pers. comm.) that rat selection of a trap type depends on the combination of traps types at one location. To avoid interaction between the two rat-trap systems, we placed alternately along the trap line either two Ezeset or two Ka Mate rat traps, plus one Victor mouse trap (regardless of the type of rat trap) in the most suitable place (flat, under cover) within 2 m from the location of each trap station. While leaving the rat traps in the open, we enclosed the mouse trap within a plastic cover of 15 cm diameter and height, with a 3-cm diameter entrance to prevent larger rats from reaching the trap. We baited all traps with cubes of raw coconut and set each trap line for two consecutive nights (derived from Rouys & Theuerkauf 2003). We set the traps in the late afternoon and checked them in the following morning. We closed the Ezeset traps during the day to avoid catching native birds and reptiles, but we left the Ka Mate traps set. While setting the Ezeset and Victor traps again in the late afternoon, we checked all Ka Mate traps for captures. Accordingly, we could distinguish between captures in the day and at night when comparing the capture rates of target species and by-catch of the different trap types. We defined any animal found alive in a trap during the morning check or, alternatively, dead but caught by a leg or the tail, as a live capture. However, there was no way to judge what proportion of trapped animals survived the strike but died later of asphyxia. Additionally, we included results on by-catch and the effect of rain from analysis of a further 74 trap lines (6976 trap nights) run in New Caledonia from 2001 to 2007, using only Ezeset traps baited with cheese.

Results

Trapping efficiency

In 2007–2010, we caught a total of 442 rodents in 2879 trap nights with the 3 different types of snap traps: 237 Pacific rats (with mass ranging from 10 g to 102 g), 194 black rats (22–255 g), 10 Norway rats (40–305 g) and 1 house mouse (16 g). Ezeset traps recorded higher capture rates of Pacific rats, while Ka Mate traps captured black rats and Norway rats more efficiently (Table 1). The size of rodents influenced capture rates, with animals under 75 g more commonly

Table 1. Mean abundance indices (AI ± 95%CI) with of Ka Mate and Ezeset rat traps on Wallis & Futuna (1146 trap nights at 12 sites) and New Caledonia (1400 trap nights at 14 sites), from 2007–2010.

	Wallis & Futuna (n = 12)			New Caledonia (n = 14)		
	Ka Mate	Ezeset	ratio	Ka Mate	Ezeset	ratio
Black rat, *Rattus rattus*						
AI_1	5.2 ± 3.8	3.1 ± 2.1	1.70	14.1 ± 6.7	7.0 ± 3.5	2.02
AI_2	8.1 ± 6.4	5.0 ± 3.6	1.61	18.2 ± 10.1	8.8 ± 4.8	2.07
AI_3	7.2 ± 5.6	4.7 ± 3.3	1.54	15.7 ± 7.8	8.2 ± 4.2	1.93
AI_4	7.2 ± 5.6	not recorded	–	15.7 ± 7.8	8.6 ± 4.4	1.83
Pacific rat, *Rattus exulans*						
AI_1	14.6 ± 4.9	21.6 ± 6.8	0.67	0.7 ± 1.0	3.1 ± 1.5	0.22
AI_2	22.2 ± 8.7	34.0 ± 11.6	0.65	0.9 ± 1.3	3.8 ± 2.0	0.24
AI_3	19.2 ± 6.8	27.9 ± 8.5	0.69	0.9 ± 1.2	3.7 ± 1.9	0.24
AI_4	19.2 ± 6.8	not recorded	–	0.9 ± 1.2	3.9 ± 1.9	0.23
Norway rat, *Rattus norvegicus*						
AI_1	1.2 ± 1.7	0.5 ± 0.7	2.53			
AI_2	2.1 ± 3.1	0.7 ± 1.0	2.94			
AI_3	2.0 ± 2.9	0.7 ± 0.9	2.80			
AI_1 of all rodents	21.0 ± 8.1	25.5 ± 8.7	0.82	14.8 ± 7.2	10.1 ± .3	1.47
AI_1 of crab by-catch	5.4 ± 3.6	3.9 ± 2.3	1.40	0.1 ± 0.3	0.0 ± 0.0	–
AI_1 of other by-catch	0.3 ± 0.6*	1.3 ± 1.9**	0.25	0.0 ± 0.0	0.2 ± 0.4**	–
AI_1 of traps sprung empty	29.0 ± 13.0	39.4 ± 15.7	0.73	13.9 ± 6.5	19.2 ± 6.8	0.72
AI_1 of traps still open	43.8 ± 17.6	29.9 ± 14.7	1.46	71.2 ± 12.1	70.5 ± 9.6	1.01
AI_1 of traps still operational	43.8 ± 17.6	not recorded	–	71.2 ± 12.1	62.2 ± 12.1	1.14

* all captures in the day, **all captures at night (traps blocked in the day).

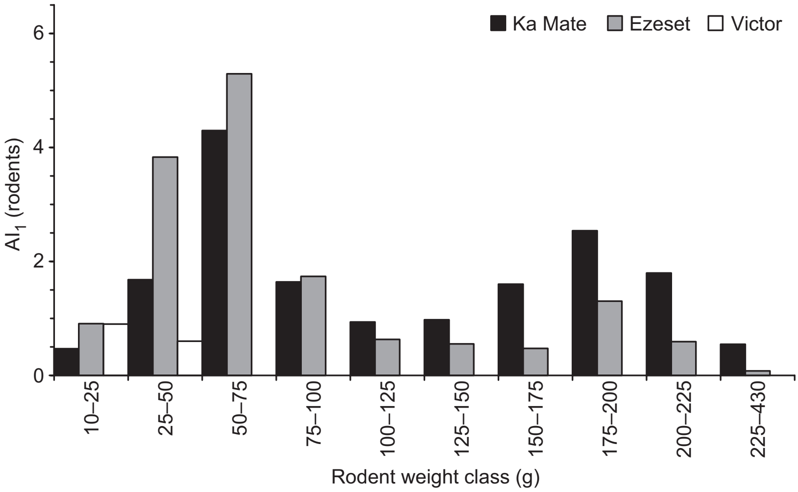

Fig. 2. Rodents caught per 100 trap nights (AI_1) in relation to their mass (31 rodents could not be weighed) in prototype Ka Mate Medium Pro Traps (211 rodents in 1280 trap nights), Ezeset Supreme Rat Traps (195 rodents in 1266 trap nights), and Victor Professional Mouse Traps (5 rodents in 333 trap nights) on Wallis & Futuna (1479 trap nights) and New Caledonia (1400 trap nights), from 2007–2010.

captured in Ezeset traps and larger rodents (especially those over 150 g) being caught more effectively in Ka Mate traps (Fig. 2). The mean mass of rodents caught in Ka Mate traps was 116 g (SD = 65 g, n = 211), compared with 81 g (SD = 54 g, n = 195) for rodents caught in Ezeset traps. Rodents caught in Victor mouse traps housed in protective trap stations with small entrances had a mean mass of 25 g (SD = 13 g, n = 5).

Ka Mate traps were sprung less frequently than Ezeset traps without catching, resulting in a greater percentage of operational traps available in the morning (Table 1). Ka Mate traps were not sprung by rainfall since ratios of traps sprung but empty were nearly equal (t-test: p = 0.619) on dry nights (0.13 ± 0.07 95%CI, n = 16) and on nights with a small amount (0.1–4 mm) of rain (0.16 ± 0.10, n = 8), whereas the proportion of Ezeset traps sprung but empty was higher (t-test: p = 0.012) on nights with 0.1–4 mm of rain (0.32 ± 0.14, n = 8) than on dry nights (0.13 ± 0.04, n = 16). In the larger 2001–2010 data set from New Caledonia with nightly (n = 166) rainfall ranging from 0 to 90 mm, the proportion of Ezeset traps sprung but empty (y) increased with increasing rainfall (x, in mm) at night: $y = 0.004x + 0.09$ ($p < 0.001$).

Ratios of abundance indices during the first and second nights of a trapping session (Table 2) were relatively even between Ka Mate and Ezeset traps. Both traps generally caught greater numbers of the predominant rat species during the first night, whereas the trend was reversed for the less common species (Table 2).

Killing efficiency

We recorded similar live capture rates for both Ka Mate and Ezeset traps: in Ka Mate traps, at least 15% of 130 black rats (11 by leg or tail, 9 by neck) and 4% of 84 Pacific rats (3 by leg or tail) were caught alive, while in Ezeset traps, at least 13% of 64 black rats (2 by leg or tail, 6 by neck) and 5% of 148 Pacific rats (7 by leg or tail) were caught alive. The mean mass of the 34 "live" caught rats that could be weighed (the other 4 were partially eaten) was however higher (t-test: p = 0.028) in Ka Mate Traps (150 g, SD = 55, n = 20) than in Ezeset Traps (99 g, SD = 68, n = 14). Rats caught alive by the neck (168 g, SD = 36, n = 14) were heavier (t-test: both p < 0.001) than rats killed outright (95 g, SD = 61, n = 368) or those caught live by the leg or tail (99 g, SD = 68, n = 19).

By-catch rate

On Wallis & Futuna, hermit crabs were present in all sampled habitats and constituted the main non-target captures in both Ka Mate and Ezeset traps during the 2007–2010 trapping sessions (Table 1). While no by-catch other than hermit crabs was caught during 552 Ka Mate trap nights, two buff-banded rails (*Gallirallus philippensis*) were killed in Ka Mate traps left set during the day (145 trap days). Other by-catch from 594 Ezeset traps nights on Wallis & Futuna during the study period included six invasive *Lissachatina* *fulica* (Gastropoda), one invasive Veronicellidae (Gastropoda), and one *Emoia nigra* (Scincidae). By-catch from 333 Victor trap nights included three hermit crabs and one buff-banded rail.

In rainforests of New Caledonia, we caught only one hermit crab in a Ka Mate trap but no other non-targets during 2007–2010. The only non-target caught in an Ezeset trap was a lizard, *Marmorosphax tricolor* (Scincidae). However, earlier rodent surveys (6976 trap nights) in New Caledonia between 2001–2007, using Ezeset traps baited with cheese, resulted in a by-catch that included one green and golden bell frog (*Litoria aurea*), one *Marmorosphax tricolor* (Scincidae), two other skinks (Scincidae), one large Orthoptera, one giant flax snail *Placostylus* sp. (Gastropoda), three yellow-bellied robins (*Microeca flaviventris*), two New Caledonian whistlers (*Pachycephala caledonica*) and one unidentified passerine bird (eaten by a scavenger).

Discussion

Trapping efficiency

Results suggest that Ka Mate traps are better than Ezeset traps at capturing large rodents and less efficient for small rodents. The reason for the lower trapping success of smaller rodents might be that they less often remove the bait completely from the trap. While this would make no difference for an Ezeset trap, even a small leftover on a Ka Mate trap would keep the trap from firing. For Ka Mate traps, the size of bait seems to have an important effect on trapping success. We, therefore, suggest that Ka Mate traps should be used in combination with other trigger or treadle rat traps to ensure small rodents are not missed in studies aimed at detecting rodent species assemblages. However, for abundance surveys (index trapping), the design and function of the Ka Mate trap provides a more reliable system, which results in reduced environmental disturbance to traps and a lower ratio of sprung but empty traps when comparing Ka Mate and Ezeset trapping results. The mass and dimensions of the Ka Mate prototype traps did not significantly differ to that of wet wooden based traps. Bearing in mind the durability of aluminium Ka Mate traps, they will be at an advantage for long-term field use. We recommend the production of a smaller version, more appropriate for use with Pacific rats and house mice. These would be more efficient for small rodents, while reducing bulk for ease of transport.

During a trapping study on a New Zealand island, Norway rats were predominantly captured during the first days, and Pacific rats were captured later, when Norway rats became rarer (Harper & Veitch 2006). On the Galápa-

Table 2. Rats caught per 100 trap nights (AI_1 ± 95%CI) with Ka Mate and Ezeset rat traps in the first and in the second night on Wallis & Futuna (1146 trap nights at 12 sites) and New Caledonia (1400 trap nights at 14 sites), from 2007–2010.

	Wallis & Futuna (n = 12)			New Caledonia (n = 14)		
	Ka Mate	Ezeset	ratio	Ka Mate	Ezeset	ratio
Black rat, *Rattus rattus*						
first night	7.6 ± 8.0	2.6 ± 2.5	2.92	15.1 ± 9.0	7.7 ± 4.5	1.95
second night	9.0 ± 6.5	7.1 ± 3.6	1.27	13.2 ± 5.6	6.3 ± 3.7	2.11
ratio	0.84	0.37		1.15	1.24	
Pacific rat, *Rattus exulans*						
first night	15.9 ± 7.1	24.3 ± 8.6	0.65	0.3 ± 0.6	3.3 ± 2.0	0.08
second night	10.6 ± 3.2	17.9 ± 7.5	0.59	1.1 ± 1.4	3.0 ± 2.0	0.37
ratio	1.50	1.36		0.25	1.10	
Norway rat, *Rattus norvegicus*						
first night	3.5 ± 5.3	0.6 ± 1.3	5.42			
second night	1.4 ± 1.7	1.3 ± 1.6	1.08			
ratio	2.50	0.46				

gos Islands, Harper and Cabrera (2010) found a similar pattern, catching first black rats and later house mice. The authors of the two studies concluded that subordinate rodent species are more often caught once the dominant rat species is removed. In general, Norway rats dominate black rats (Barnett & Spencer 1951, Barnett 1955) and black rats dominate Pacific rats (McCartney & Marks 1973, Yom-Tov *et al*. 1999). However, in this study, we caught the most common species first, which was the Pacific rat on Wallis & Futuna and the black rat on New Caledonia. If the dominant rat species were caught first, we would have expected Norway rats and black rats to be caught first and Pacific rats later. This was however not the case, as Pacific rat capture rates on Wallis & Futuna were high on the first day and noticeably lower the second day. Our findings, therefore, suggest that the underlying cause of a particular species being caught at the beginning of a trapping session might not be competition between a dominant and a subordinate species. It is more likely that the capture rate follows the "first come, first served" rule, i.e. the more abundant species is caught first, simply because individuals of this species have a higher chance of locating the traps first.

We set traps for only two days, so behavioural differences among the rat species might have affected the trapping results. Tobin *et al*. (1994) reported that once a trap has captured a rat, the chance it will trap subsequently the same species is higher than the chance of capturing another species. This might be because of behavioural interactions between species, but also might be caused by differences in habitat selection among the rat species. A larger data set of rat trapping with Ka Mate Medium SafeT-catch traps on Wallis & Futuna in 2009–2011 over periods of up to 17 days (authors' unpubl. data), indicated that the proportions of species change little over this period, and that a period of two days was representative for the proportion averaged over 17 days. While the duration of trapping does therefore not seem to influence the proportion of rat species, the results of this study showed that the trap system does: Ka Mate traps catch a higher proportion of larger species, while Ezeset traps catch a higher proportion of Pacific rats. As we do not know the real proportions of rats, and abundance indices are never fully representative for densities (Tanaka 1960), we cannot state which trap system better represents the true rat densities.

Killing efficiency

A major consideration in Ka Mate trap design was the reduction of live capture and by-catch (Thomas *et al*. 2011). However, in this study the proportion of live captures in Ka Mate traps was similar to that of Ezeset traps, but occurred with distinctly different mass classes between the two traps. Ka Mate traps caught and killed large-sized rats that were often live-captured in Ezeset traps, but Ka Mate traps live-captured very large rats that would simply have escaped from Ezeset traps. Live capture of at least some rats seems unavoidable in the prototype Ka Mate traps and we suggest, therefore, that spring power might be reconsidered during commercial manufacture. This would better ensure successful application of Ka Mate traps as an efficient new tool for use in eradication or control of large rats such as black rats and Norway rats.

By-catch rate

Ka Mate traps did not capture non-target species other than land crabs at night. Ezeset traps, however, caught a range of non-targets, including invertebrates, frogs, lizards and birds in this study. Hermit crabs are widespread and numerous on Wallis & Futuna and Ka Mate traps recorded even higher crab capture rates than Ezeset traps. This is probably due to Ka Mate being a more powerful trap and, therefore, more liable to catch and crush hermit crabs or sever legs. Crabs, however, would often depart from an Ezeset trap without even losing a limb.

Two buff-banded rails were caught by Ka Mate traps on Wallis & Futuna, during a period when the traps remained baited and set during daylight hours (equivalent of 145 trap days), likely because rails are capable of removing bait from the traps. Although Ka Mate traps do not capture animals that step on the traps by chance, it is not possible to avoid killing species that take the bait. In areas with high densities of non-target species that are attracted by the bait, special measures should be put into place to keep vulnerable fauna away from the traps. Traps could be housed in protective stations designed to exclude specific non-targets, placed on platforms or screwed vertically onto tree trunks (accessible to rats but out of reach of ground dwelling fauna such as rails), or alternatively baits that attract rodents but not non-target species could be used.

Abundance indices

Because Ka Mate traps function differently from traditional snap traps, abundance indices that do not consider unavailable traps (AI_2 and AI_3) do not allow comparison between the different trapping systems. However, improving the original equations including the number of unavailable traps in the final calculation (AI_4) solved this problem. Moreover, AI_4 provides similar results for Ezeset traps as AI_2, which makes it approximately comparable to previous studies that used trigger traps. We recommend the use of AI_4 as a standard calculation for future index trapping of rats, regardless which kind of trap is used.

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