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What factors affect the density of cane toads (*Rhinella marina*) in the Solomon Islands?

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Abstract. Cane toads (*Rhinella marina*) were introduced to the Solomon Islands in the 1940s, and quickly spread across the archipelago. Between May 2009 and August 2012, cane toads were recorded on 11 of 13 islands surveyed, and the densities of toads were estimated by distance sampling on seven of these islands. Modified Akaike's Information Criterion (AIC_c) tests were used to find the most parsimonious model for cane toad density in the Solomon Islands. The results showed that mean toad density was higher on Gatokae and Guadalcanal than on Bougainville, Choiseul, Kolombangara and Rendova. A plausible explanation for this is that Guadalcanal had an abundance of breeding sites, and that Gatokae may have been recently colonised with a typical sharp rise in toad densities. The model also showed that mean toad density was higher in coastal forests than in other forest types (e.g lowland, hill and montane forests). Coastal forests have higher disturbance levels as a result of villages and towns. Disturbance was associated with increased toad densities in the model. These findings suggest that cane toad management efforts should target coastal forests and disturbed areas along roads and tracks leading to important biodiversity reserves.

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Introduction

Accurate density estimates are critical to studies on pest control and the management of wildlife (Lampo and Bayliss 1996). The cane toad (*Rhinella marina*) is a large anuran native to tropical rainforests of Central and South America (Greenlees *et al.* 2006). The species is now widespread in Oceania and the Caribbean, having been introduced to the Solomon Islands, Australia, Hawaii, Fiji, Papua New Guinea, Barbados, Puerto Rico and Jamaica, as a biological control agent (Lever 2001, 2003).

Cane toads have been in the Solomon Islands for more than 70 years. They were first introduced to the Russell Islands and Guadalcanal in the 1940s by Levers Plantation Ltd to help control beetles that were causing damage to coconut plantations (Lever 1942; Easteal 1981). They were also taken to Aligegeo outside Aoke (Auki), Malaita, to help control mosquito larvae but they reportedly poisoned the water and killed introduced *Tilapia* and other fish (BSIP-NS 1969). Subsequently, schoolboys from Aoke Experimental School (later King George VI School) at Aligegeo transferred toads to Pawa on Uki (Ugi) Island. In 1959 or 1960, toads were released at Pamua (Makira Island), and in a matter of months they spread along the coast as far as Kirakira (BSIP-NS 1969). Santa Cruz remained toad-free due to the local council passing legislation to prevent their import (BSIP-NS 1969). Lever (2001, 2003) reported toads being on Guadalcanal (Honiara), Malaita, Russell Islands (Banika), Florida Island group (Gavutu), Vanikoro, Buka, and Ugi (Pawa). Today they have spread to all large islands (Lever 1942), and some smaller outer islands (Lever 2003; Heinsohn 2006) of the Solomon Islands archipelago.

Introduced populations of the cane toad have the potential to reach densities far greater than those encountered amongst native populations in South America. Studies have shown population densities to be greater in Australia (2138 ha^{-1}) (Freeland 1986) compared with the species' native range (1225 ha^{-1}) (Lampo and Bayliss 1996). The impacts of climate change may also mean more recurrent and hotter wild fires, decreasing connectivity between habitats that are already fragmented, resulting in the expansion and wider distribution of cane toads (WWF 2008). Location and access to sufficient or insufficient rain-fed ponds under a changing climate may also influence toad densities and distribution (Kearney *et al.* 2008).

The introduction of cane toads has had varying effects on native wildlife in other countries in the Oceania region. The cane toad is toxic to vertebrates, with all life stages containing bufadienalides (Phillips and Shine 2004). Where introduced, the poisoning of native predators through consumption of various life stages has been one of the most noticeable impacts (Vallortigara *et al.* 1998; Phillips and Shine 2005; Crossland *et al.* 2008). Taxa such as varanid and scincid lizards, elapid

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snakes, freshwater crocodiles and dasyurid marsupials are most affected (Letnic and Shine 2008; Shine 2010). Toads have been credited with monitor declines in New Guinea and the Solomon Islands (Kraus 2009). In New Guinea, the introduction of cane toads in the 1930s has resulted in a decline in the population of the Papuan black snake (*Pseudechis papuanus*) and deaths of New Guinean marsupial carnivores (*Dasyurus albopunctatus*) (O'Shea 2008).

Cane toads are also predators of many species of native insects (Zug and Zug 1979). In experimental trials, Greenlees *et al.* (2006) noted a marked decrease in invertebrate abundance and species richness due to predation by toads. In some cases, toads can have positive impacts. For example, a study in cacao plantations on New Britain found pest species in the stomach of cane toads, which suggests that cane toads do wield some control over pests. The same study reported other dietary items of toads, including ants (comprising 46% of volume), snails (comprising 42% of volume), and other insect orders (comprising the remaining 12% of volume) (Bailey 1976).

Almost nothing is known of the distributional ecology or impacts of cane toads in the Solomon Islands (Bailey 1976; Shine 2010). Recent surveys in the Solomon Islands have recorded deaths of giant Australasian centipedes (*Ethmostigmus rubripes*) after ingesting cane toad tissues (Pikacha and Sirikolo 2012). Previous research has revealed poisoning of snakes and water monitors (*Varanus indicus*) following toad ingestion (Cain and Galbraith 1957).

The population of cane toads was estimated on nine islands in the Solomon Islands archipelago to identify important environmental and ecological factors affecting toad densities. This knowledge may lead to strategies for managing this invasive species in the Solomon Islands.

Methods

Study area

Between May 2009 and August 2012 densities of cane toads were recorded at 29 transects in 10 geographic areas on nine islands: Bougainville (6°14′40″S, 155°23′02″E; $n = 3$), Choiseul (7°20′48″S, 157°23′12″E; $n = 3$), Gatokae (8°46′31″S, 158°11′20″E; $n = 1$), Guadalcanal (9°25′53″S, 160°01′37″E; $n = 2$), Kolombangara (8°02′27″S, 157°06′26″; $n = 2$), Malaita (09°14′04″S, 161°02′41″E, $n = 7$; 08°29′54″S; E160°53′13″E, $n = 2$), Ranongga (08°04′10″S, 156°33′39″E; $n = 2$), Rendova (8°28′18″S, 157°21′08″E; $n = 5$), and Tetepare (08°42′28″S, 157°30′06″E, $n = 2$) (Fig. 1). These islands represent a significant proportion of the archipelago, spanning more than 500 km. The highest elevation sampled was Rendova Peak (980–1033 m above sea level), Rendova Island, and Ohumae, West Are'Are (640 m above sea level), Malaita Island. The presence of cane toads was reported at four other geographic areas (Isabel ($n = 8$), New Georgia ($n = 2$), Vangunu ($n = 1$) and Vella Lavella ($n = 4$)) islands (Table 1). However, no abundance records were made at these transects, and so they were excluded from the model tests, which used the measure of density.

Factors assessed

Invasive species are known to exploit altered landscapes or disturbed areas (Semeniuk *et al.* 2007; Urban *et al.* 2008), and undisturbed habitats (Bradshaw *et al.* 2007). Previous studies have shown that toads select sites based on habitat characteristics, suggesting that it might be possible to manipulate those characteristics to either enhance or reduce toad densities (Hagman and Shine 2006).

Based on what we know about cane toads and the literature (Seabrook and Dettman 1996; Burnett 1997; Foufopoulos and Richards 2007; Semeniuk *et al.* 2007), a total of three continuous and seven nominal factors were recorded in this study (Table 2). They included forest type, shrub cover, leaf litter, soil moisture, disturbance, percentage canopy understorey and overstorey, landform, and islands.

To determine what areas cane toads utilised, two levels of disturbance were measured: disturbed (including old roads, trails or gardens) and undisturbed areas or areas free of visible disturbance (Brown *et al.* 2006). Population estimates based on density data in different disturbed areas are necessary to evaluate management approaches to control toads (Lampo and Bayliss 1996).

Factors used as predictors in the model are listed in Table 2. Frog diversity and other factors such as forest type were not significant factors in pretests, hence were excluded from model tests. Seven islands were included in the analysis. Rendova and Tetepare were excluded because no cane toads were recorded on these islands. Island is placed in the model as an effect. The random effect on the other hand, does not consider how many toads are found on a particular island, islands will have different baseline populations. The emphasis is on the variability in the baseline rather than in the particular baseline of one island against the other. However islands contacted in this sampling had very different densities. In addition, placing island in the model was based on initial tests that were fitted, where there were terms for many of the islands. Initially islands were distinct and later were pooled together based on the similarity of the parameters.

The structure and composition of vegetation communities throughout the Solomon Island archipelago is remarkably consistent (Whitmore 1966, 1969; Hancock and Henderson 1988). This allows comparison of density estimates derived from the same vegetation type on different islands. Six main forest types have been identified, five occurring at transects in the study sites: coastal forests, freshwater forests, lowland rain forests, hill forests and montane forests. Lowland rain forests occupy altitudes of 5–70 m above sea level. These are often subject to a high degree of disturbance by cyclones and human activities. Hill forests generally occur up to an altitude of ~600 m above sea level. They are complex in structure and exhibit varying tree heights and canopy density. Montane forests generally occur above 600 m above sea level on ridge tops and mountain summits. The canopy is very compact and dense with lighter tree crowns, and trees are covered in dense mats of epiphytes.

Line sampling for density

In total, 29 transects were sampled on nine islands (Fig. 1; Table 2) in five habitat types (Table 2). Sampling was conducted along 100-m transects. Each transect was traversed on foot by the first author (PP), and a head torch (Petzl Tikkina Led Head Lamp, Grenoble, France) was used to detect cane toads. The perpendicular distance from the transect to the toad(s) was

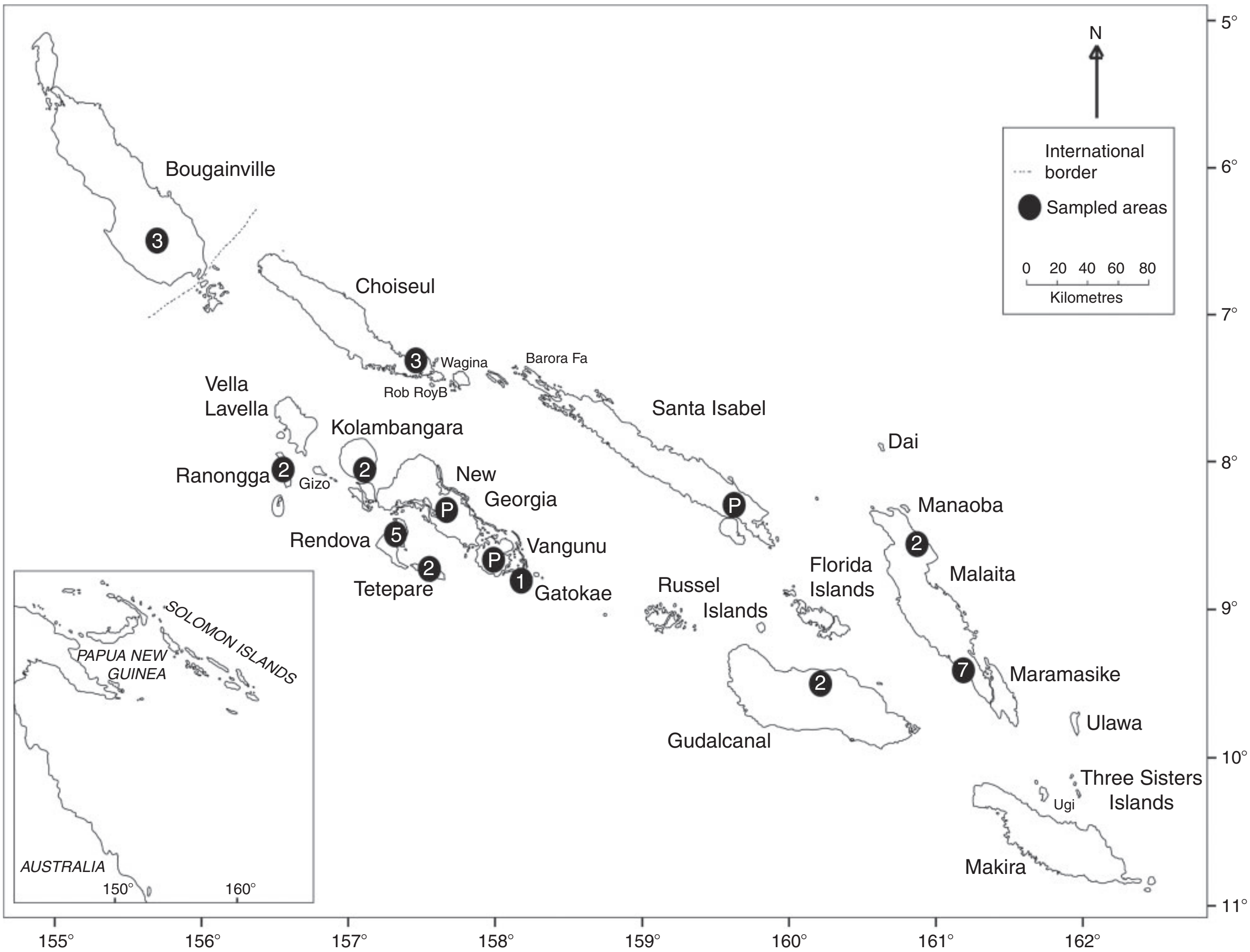

Fig. 1. Map showing 10 geographic areas sampled for cane toads on nine islands in the Solomon Island Archipelago. The number in the circle refers to the number of transects with density estimates in the area. The 'P' in the circles represent a presence of cane toads during surveys the site, but no density estimates were made.

measured using an Ultrasonic Laser Point Distance Measurer (UK Parts Deal, Hong Kong), which is recommended to ensure adequate accuracy (Thomas *et al.* 2010). The walk was conducted between 1730 and 2315 hours, with an average of 58.81 ± 1.47 (s.e.) minutes being spent at each transect. The software DISTANCE (Buckland *et al.* 2001; Thomas *et al.* 2010) was used to estimate density. A global detection function has been used in other studies with small sample size (Reidy *et al.* 2011), and was used in this study.

Statistical analysis

To identify the best regression model (e.g. subset of predictors), AIC_c, a modified criterion of AIC (Akaike's Information Criterion) was used to identify the best-fitting model (Anderson *et al.* 2000; Burnham and Anderson 2002). This procedure provides an effective means of measuring one model against another based on the number of parameters, the standard error (residual sums of squares) and the sample size (Mazerolle 2006). Subset regression was used to identify a series of potential candidate models and to filter out the irrelevant ('noisy') data (Anderson *et al.* 2000). AIC was defined as:

$$AIC = N(ln(\text{Residual}\,SS/N)) + (2 * p)$$

where N is the sample size and p is the number of parameters (Webster and McBratney 1989). And AIC_c is defined as:

$$AIC_c = AIC + 2{*}p\,(p{+}1)/(N - P - 1)$$

(Anderson *et al.* 2000; Burnham and Anderson 2002).

With this approach, different models are weighed by the amount of variation explained and the complexity of the model (such as the number of explanatory variables, p). The strength of support for an AIC_c value was assessed by ΔAIC_c (e.g $AIC_c = AIC_i - AIC_{min}$) and Akaike weights (Burnham and Anderson 2001). Models with ΔAIC_c values of 0–2 give similar support (Burnham and Anderson 2001). An Akaike weight represents the relative likelihood of the model, given the data. The model

Table 1. List of islands in the Solomon Islands where *Rhinella marina* has been recorded in this study
Where available, the sources of the introduction, date of the introduction, and source of the data are also shown

Island	Island size (km^2)	Source of introduction	Date of introduction	Numbers introduced	No. of transects in this study	Transects where toad are present in this study	Source
Bougainville	9300	Unknown	Before 1945	Unknown	3	3	Zug *et al.* (1975), this study
Buka		Fiji	Before 1945	Unknown	Unknown	Unknown	Zug *et al.* (1975)
Central island group (Nggela, Russell and Savo Islands)	615	Guadalcanal	Unknown	Unknown	Unknown	Unknown	Islands Protectorate News Sheet 31 March 1969, Lever (2001)
Choiseul	3294	Kolombangara	1990s	Sack full introduced to south Choiseul	13	13	Local informant, this study
Gatokae	100	Guadalcanal	Unknown	Unknown	14	2	Local informant, this study
Gavutu	3	Fiji	Before 1944	Unknown	Unknown	Unknown	Lever (1945), Brown (1952)
Guadalcanal	5302	Fiji	1940	Unknown	9	9	Lever (1945), Tanner (1951), this study
Isabel	2999	Unknown	Unknown	Unknown	8	8	This study
Kolombangara	705	Guadalcanal	Unknown	Unknown	23	8	This study
Nendo	505	Unknown	Unknown	Unknown	Unknown	Unknown	Lever (2001)
Makira	3190	Guadalcanal	Unknown	Sack full	Unknown	Unknown	Islands Protectorate News Sheet 31 March 1969, Heinsohn (2006)
Malaita	4307	Fiji	Before 1952	Unknown	9	9	Brown (1952), this study
New Georgia	2037	Guadalcanal		Unknown	9	2	This study
Rendova	400	Unknown	Unknown	Unknown	7	4	This study
Santa Ana	12	Makira		Unknown	Unknown	Unknown	Heinsohn 2006;
Ugi	50	Malaita	Unknown	Unknown	Unknown	Unknown	Islands Protectorate News Sheet 31 March 1969, Lever (2001)
Utupua	69	Unknown	Unknown	Unknown	Unknown	Unknown	Lever (2001)
Vangunu	543	Unknown	Unknown		8	1	This study
Vanikoro	173	Fiji	Before 1956	Unknown	Unknown	Unknown	Lever (2001)
Vella Lavella	640	Unknown	Unknown	Unknown	4	4	This study

Table 2. Factors and variables used in the statistical model analysis
As well as the nominal factors listed below, one continuous variable was used: survey effort per transect (mean ± s.e. = 58.81 ± 1.47 min, range = 24–96 min)

Nominal factors	Parameter	No. of values	% transects
Disturbance levels	Disturbed	15	60
	Undisturbed	10	40
Island	Bougainville	3	10
	Choiseul	3	10
	Gatokae	1	3
	Guadalcanal	2	7
	Kolombangara	2	7
	Malaita	9	31
	Ranongga	2	7
	Rendova	5	17
	Tetepare	2	7
Forest type	Coastal	3	12
	Freshwater marshes	2	8
	Lowland	11	44
	Hill and ridge	6	24
	Montane	3	12

factors that affect cane toad density were graphed with error bars representing standard deviation (s.d.).

Results

Cane toads were recorded on 25 of the 29 transects on seven islands, and toad densities estimated. Canopy at the transects sampled ranged from 20 to 70% cover (average 55.64 ± 0.67, and understorey from 30 to 60% cover (average 48.00 ± 0.68). No cane toads were found on two transects on Tetepare, and another two transects on Ranongga Island (Fig. 1). On the basis of these results and findings in the literature, an updated summary of cane toad distribution in the Solomon Islands is presented in Table 1.

The average density of cane toads recorded across all positive transects was 25.62 ha^{-1}. The lowest density was 6.34 ha^{-1}, recorded in montane forests on Rendova and Malaita islands, and the highest was 76.09 ha^{-1}, recorded in disturbed lowland forest on Kolombangara island.

In subset regressions with the inclusion of 'islands' as variables, Gatokae and Guadalcanal Islands had the same effect on toad densities. Hence, in subsequent statistical model testing, these two factors were combined to form a single predictor for the best-fit model analysis. The analysis indicated strong support for a statistical model based on the lowest AIC_c that showed the predictors 'disturbance', 'islands', and 'coastal forests' (Table 3) as significant factors of toad densities. The formula for the best-fit model was:

$$\log(\text{toad density}) = 1.02 + 0.493(\text{disturbance}) + 0.51(\text{Gatokae or Guadalcanal}) - 0.18(\text{Malaita}) + 0.24(\text{coastal forest})$$

The Akaike weight for the best-fit model was 0.81. The model was also supported by an R^2 of 88% and adjusted R^2 of 85.6% (Table 3). All the factors in the model were statistically significant (Table 4).

Disturbance

Habitat disturbance had the greatest impact on toad density in the model. Toad density was predicted to be 3.11 times greater in disturbed than non-disturbed habitats (Fig. 2, Table 4). Predicted densities in disturbed habitats ranged from 25.65 ha^{-1} to 40.43 ha^{-1} (average 32.20 ha^{-1}) and undisturbed areas from 7.78 ha^{-1} to 13.79 ha^{-1} (average 10.35 ha^{-1}) (Fig. 2).

Islands

Toad densities were highest on Gatokae or Guadalcanal, with values ranging from a minimum density of 21.01 ha^{-1} to a maximum of 52.52 ha^{-1} (average 33.22 ha^{-1}). Malaita Island supported lower toad densities of 5.16–8.93 ha^{-1} (average 6.79 ha^{-1}) (Fig. 3, Table 4). Densities were more variable on Bougainville, Choiseul, Kolombangara, and Rendova, ranging between a minimum of 7.78 ha^{-1} and a maximum of 13.79 ha^{-1}. The average density recorded for these four islands was 10.35 ha^{-1}.

Forest type

Forest type was a significant factor in the model (Fig. 4). Coastal forests had higher toad density (18.08 ha^{-1}) than non-coastal forests (freshwater, lowland, hill and montane forests) (10.35 ha^{-1}). Densities in coastal forests ranged from 9.93 ha^{-1} to 32.94 ha^{-1} (average 18.08 ha^{-1}). In non-coastal forests they ranged from 7.78 to 13.79 ha^{-1}, and on average supported lower densities (10.35 ha^{-1}) than coastal forests (Fig. 4, Table 4).

Discussion

This study showed that mean density of cane toads in sampled habitats in the Solomon Islands was 10.35 ha^{-1}. Toads are known to reach astonishing densities in suitable habitat within their introduced range (Phillips *et al.* 2003). An estimated density of 2134 individuals ha^1 was reported in Australia (Freeland 1986). The density of toads in the Solomon Islands archipelago is similar to reported densities in Papua New Guinea, with approximately 3 toads ha^{-1} in forests, 30 ha^{-1} in savannahs and 300 ha^{-1} in urban regions (Zug *et al.* 1975). The selected model clearly shows that mean density of cane toads was most influenced by disturbance regimes and, to a lesser extent, by forest type and islands.

Densities of cane toads were shown to be greater in disturbed than in undisturbed environments in the Solomon Islands. The preference of cane toads for disturbed habitats, including roads and tracks, is well documented in the Australian literature (Lampo and Bayliss 1996; Seabrook and Dettman 1996; Urban *et al.* 2007). Furthermore, toads have been recorded to disperse more rapidly in open disturbed areas than in thick vegetation (Brown *et al.* 2006). Linear disturbances in landscapes such as

Table 3. Model selection results for predicting densities of cane toads in the Solomon Islands

Model	Parameters (p)	R^2	Adjusted R^2	AIC_c	Δ_i	w_i	F	P
Log(toad density) = 1.02 + 0.493(disturbance) + 0.51(Gatokae or Guadalcanal) – 0.18(Malaita) + 0.24(coastal forest)	5	88.0%	85.6%	−88.53	0.00	0.81	36.81	<0.0001
Log(toad density) = 1.00 + 0.51(disturbance) + 0.59(Gatokae + Guadalcanal) – 0.18(Malaita) + 0.23(coastal forest)	6	88.3%	85.2%	−85.57	−2.95	0.19	28.69	<0.0001
Log(toad density) = 1.04 + 0.53(disturbance)	8	87.1%	81.8%	−74.78	−10.79	0.005	17.32	<0.0001

Table 4. Statistics of predictor values and transformed (from natural log) densities of predictor values in the model

Note: predictors are multipliers of the constant. Upper and lower refer to the upper and lower 95% confidence intervals for the estimated derived multiplier parameters. T is the test statistic for each parameter estimate (the coefficient divided by its standard error).

Predictor	Coef.	s.e. of Coef.	Density (ha^{-1})	Lower	Upper	T	P
Constant	1.01514	0.05961	10.35	7.78	13.79	17.03	<0.0001
Disturbance	0.49275	0.06646	32.20	25.65	40.43	7.41	<0.0001
Gatokae or Guadalcanal	0.50624	0.09399	33.22	21.01	52.52	5.39	<0.0001
Malaita	−0.18328	0.06849	6.79	5.16	8.93	−2.68	0.015
Coastal forest	0.2422	0.1004	18.08	9.93	32.94	2.41	0.026

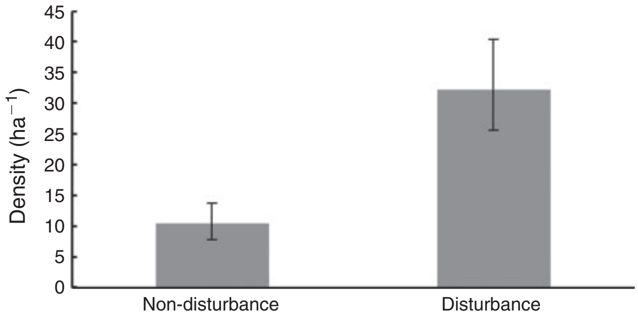

Fig. 2. The effect of disturbance on estimated toad density with other fixed effects (islands, forest type) adjusted to zero. The error bars indicate 95% confidence intervals.

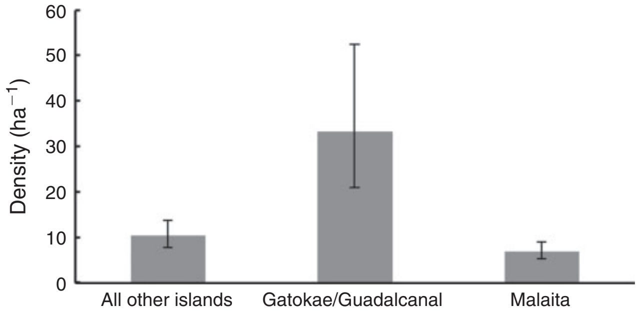

Fig. 3. The effect of island on estimated toad density with other fixed effects (disturbance, forest type) adjusted to zero. The error bars indicate 95% confidence intervals.

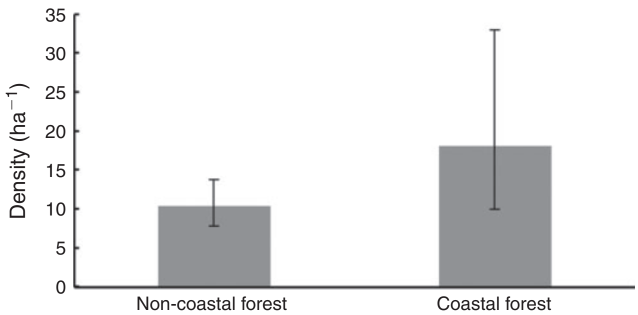

Fig. 4. The effect of forest types on estimated toad density with other fixed effects (disturbance, islands) adjusted to zero. The error bar indicates one standard deviation.

trails, roads, and railway lines are known to facilitate toad colonisation (Andrews *et al.* 2008; Van Der Windt and Swart 2008). Toads are known to select breeding sites in open disturbed areas consisting of gently sloping banks and shallow still water (Semeniuk *et al.* 2007).

Gatokae and Guadalcanal Islands were found to support the highest densities of cane toads. Guadalcanal is the site of the first introduction of cane toads to the Solomon Islands (Lever 1942); it is likely that populations rapidly increased here before they spread to other islands. In addition, the survey sites on this island were located close to the capital city (Honiara). These sites were very disturbed, with many areas of inundation during the wet season ideal for toad breeding sites. It is not known when toads arrived on Gatokae. A plausible explanation for Gatokae having high mean toad density could be that its colonisation was a recent event. Previous studies conducted in Australia have shown that local toad populations rapidly increase after a recent colonisation and remain high for more than a decade relative to areas that have long been colonised (Freeland 1986). Gatokae is also characterised by low elevations, high temperatures and increasing disturbed patch connectivity caused by logging (Bennett 2000; Bayliss-Smith *et al.* 2003; Morrison *et al.* 2008; Pikacha 2008). These factors are known to increase toad abundance (Urban *et al.* 2008).

Toad densities were lower on Bougainville, Choiseul, Kolombangara and Rendova islands than on Guadalcanal and Gatokae. On Bougainville, Choiseul, and Rendova, most surveys were conducted in relatively intact lowland and montane forests. For example, three of five sites on Rendova were located in montane forests, the other two in overgrown secondary forests at a small village dam. Transects on Choiseul were in lowland areas, with comparatively fewer villages when compared with transects on Kolombangara. Sampling on Bougainville was conducted in a cocoa plantation buffered by old-growth forest, on slopes lacking stagnant water, which are suitable for toad breeding (Hagman and Shine 2006).

Sampling on Malaita took place in montane and lowland forests that lacked large water bodies or stagnant pools. All the streams near (20–30 m from) each transect on Malaita were small and fast-flowing. It is plausible that lack of breeding sites explains low toad densities. In addition, intact forests are known to act as barriers to toads spreading in Fiji (Morrison *et al.* 2004).

The absence of toads from Tetepare and Ranongga Islands is noteworthy. Tetepare is only 2.76 km from Rendova Island where toads are present. The absence of toads on Tetepare is consistent with previous findings (Read and Moseby 2006). This finding has provided an important update of the toad-free status of these islands.

This study recorded higher densities of toads in coastal forests than in other forests (lowland, hill and montane). In the Solomon Islands, houses and development tend to be concentrated in coastal areas, increasing the level of disturbance and suitability for cane toads. Coastal areas also offer a higher availability of breeding sites for cane toads to spawn, with many fresh and saline permanent still and slow-flowing water bodies (Hagman and Shine 2006; van Winkel and Lane 2012). Such water bodies are known to offer ideal breeding sites for toads (Pikacha *et al.* 2008). Toads are known to selectively oviposit in shallow pools with unvegetated and gradually sloping mud banks (Hagman and Shine 2006). Similarly, in Australia, toads have been recorded in higher densities in coastal floodplains, wetlands and woodlands (Greenlees *et al.* 2006; Urban *et al.* 2008). Toads are capable of persisting in coastal habitats even in the absence of fresh water due to a unique ability to spawn in saline water (Rios-López 2008).

While the data in this study cannot explicitly support the notion that cane toads do impact biodiversity in the Solomon Islands, the data demonstrate that toads have the ability to disperse widely and to reach even remote sites. Toads have not previously been recorded in montane habitats in the Solomon Islands (Pikacha*et al.* 2008). These surveys detected cane toads in the undisturbed, high-elevation forests on both Rendova and Malaita Islands. Cane toads are rarely found in montane forests that lack temporary pools. However, in Fiji, toads have been recorded at Lake Tagimaucia crater, a tropical highland lake and freshwater habitat (820 m above sea level) (Southern *et al.* 1986) and more recent surveys have recorded them in montane habitats (Morrison and Nawadra 2009). Similarly, in Papua New Guinea, van Winkel and Lane (2012) detected cane toads in montane forest and they have also been found in the Nakanai Mountains on New Britain, albeit in relatively low densities (Foufopoulos and Richards 2007).

Management implications

The results of this study are useful for developing strategies for managing the impacts of this invasive species. Given that disturbed habitats appear to support the greatest densities of toads, control efforts should concentrate in these areas, and especially along roads and tracks that may facilitate toad dispersal. Also, maintaining low cane toad densities in extensive undisturbed lowland and hill forests would help offer a buffer against migrating toads, particularly into montane forests. This can be achieved by the preservation of intact forest canopies because this has already been shown to prevent the invasion of cane toads and other invasive vertebrates in Fiji, tropical north Queensland, and New Guinea (Schultze-Westrum 1970; Morrison *et al.* 2004; Olson *et al.* 2006; Tucker and Simmons 2009).

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