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Frogs under friendly fire: How accurately can the general public recognize invasive species?

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ABSTRACT

Members of the general public interact with wildlife in many ways, and an inability to distinguish between species can have significant implications for conservation. For example, attempts by environmentally-concerned private citizens to control invasive species may cause collateral damage unless people can reliably distinguish native fauna from the invader. We tested the Australian public's ability to distinguish invasive cane toads (*Bufo marinus*) from native frogs at egg, tadpole, subadult and adult life-history stages. Errors were common, especially for eggs and tadpoles (27–31% error rates) and less so for subadult and adult toads and frogs (5–43% error rates). Accuracy of identification was higher in people living in areas where toads occur (compared to other parts of Australia or overseas), and similar in men and women (but with a decrease in older men). Ability to identify anurans was increased by toad-identification awareness programs and membership of "toad-busting" community groups, but direct killing of cane toads by the general public may inflict substantial "friendly fire" on native frogs. In the absence of any clear evidence for ecological benefits from toad-killing, we suggest that such collecting activities should be conducted only in areas where toads are known to occur, and under the supervision of trained personnel (to identify any anuran before it is killed), rather than as an *ad hoc* activity pursued independently by local residents. More generally, conservation activities that involve public participation should carefully evaluate the potential rates and consequences of species misidentification by well-intentioned but untrained people.

1. Introduction

Interactions between wildlife and members of the general public have a central role in many conservation issues, and play out in complex ways. For example, public support may be critical to conservation-oriented projects (e.g., protection of wilderness areas, habitat restoration of degraded sites, consultation about development proposals with environmental consequences: Whelan and Lyons, 2005; Cousins et al., 2008; Decker et al., 2010), but equally, human activities may threaten species persistence (e.g., through pollution, habitat degradation, over-harvesting: Venter et al., 2006; Shao, 2009). In cases where the general public interact directly with wildlife, one critical issue involves the accuracy with which people can distinguish species in different categories – for example, feral *versus* native, common *versus* rare, or protected *versus* not (Stelfox et al., 2001; Ceballos and Fitzgerald, 2004; Gong et al., 2009). Misidentification may be common: for example, most duck-hunters on the Mississippi Flyway could identify common waterfowl species, but not the females of rarely-encountered taxa (Wilson and Rohwer, 1995); and most Alberta anglers had difficulty distinguishing protected from non-protected salmonid species, creating a significant over-harvesting problem (Schmetterling and Long, 1999; Stelfox et al., 2001). Mistakes in identifying plant species can lead to inadvertent spread of unwanted (potentially invasive) taxa in the course of commercial horticultural activities (Maki and Galatowitsch, 2004).

An inability to correctly identify wildlife species can have a range of consequences. Unintentional killing of protected species by hunters and fishermen (above) is the most obvious such case, but others include public health: for example, an inability of people to identify snakes can create problems in snakebite management (Morrison et al., 1983; but see Corbett et al., 2005 for a counter-example). One interesting category involves misidentifications by members of the general public who are engaged in activities designed to contribute specifically to conservation. Errors in faunal identification can compromise the usefulness of surveys that depend upon public participation, such as those to determine which species of birds are killed by domestic cats (identification mistakes were frequent: Lepczyk et al., 2003) and to record patterns of distribution of anurans (even experienced volunteers

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in a Michigan survey often were unable to correctly identify toad calls: Genet and Sargent, 2003). The current paper focuses on another activity whereby members of the general public volunteer their time and effort to address a conservation issue: that is, to help local ecosystems by reducing the abundance of invasive species.

People involved in volunteer-based activities to cull feral pests talk of "waging a war" on the invasive pest (e.g., Bright, 1998; Mack et al., 2000; Baskin, 2002; Chew and Laubichler, 2003; Larson, 2005). Accordingly, invasive-species control often relies upon military concepts such as targeting the enemy's weak points (Hagman et al., 2009; Ward-Fear et al., 2009). Inevitably, some of the problems that beset military strategists also bedevil invasive-species control. One problem in warfare involves "friendly fire", the inadvertent killing of one's allies in the belief that they are the enemy (Shrader, 1982; Lippman, 1991). Avoiding such collateral damage is a major theme of modern biocontrol. For example, the use of generalist diseases, parasites, predators or herbivores to target an invasive species would not be countenanced by regulatory authorities (Thresher and Bax, 2006; Henderson and Murphy, 2007).

The risks of "friendly fire" are less evident to some members of the general public attempting to eradicate invasive species (both plant and animal) by direct killing of the exotic taxon (e.g., Northern Australian Frogs Database System, 2009). The effectiveness of those activities is rarely evaluated, and in some cases the effort may be compromised by an inability to distinguish the invader from superficially similar components of the native fauna or flora. For example, similarity in common names and general appearance has led to many cases of invasive Indian Myna Birds (*Acridotheres tristis*) being confused with native Noisy Minor Birds (*Manorina melanocephala*) in eastern Australia (Lloyd, 2006; WetlandCare Australia, 2009; Mid North Coast Indian Myna Project, 2009). In Europe, control of invasive Asian Longhorn Beetles (*Anoplophora glabripennis*) is made more difficult by the problems of distinguishing this taxon from native wood-boring beetles (MacLeod et al., 2002). In the eastern USA, mistaken identification of invasive plants as natives is widespread, impeding attempts by community groups to restore native vegetation (Sarver et al., 2008).

Native to Central and South America, cane toads (*Bufo marinus*; = *Rhinella marina* under the nomenclatural scheme of Pramuk et al., 2008) were deliberately translocated to Australia in 1935 for biocontrol of insect pests (Lever, 2001). The toads have subsequently spread over more than a million square kilometers of Australia, killing native predators that attempt to prey on them but cannot tolerate the toads' powerful toxins (Phillips et al., 2003; Smith and Phillips, 2006; Griffiths and McKay, 2007; Letnic et al., 2008). The cane toad invasion has aroused deep public antipathy (Lever, 2001; White, 2007; Saunders et al., 2010; Shine, 2009), fostering a widespread belief that local communities can help by killing toads through group activities and also through individual action.

Clearly, "friendly fire" from toad-control activities might pose a risk to native frogs. Pilot surveys by one community group suggested that 74 of 82 reports of "cane toads" were native frogs (and in one case, a blue-tongue lizard; White, 2007). Similarly, many of the "toads" collected by the public and brought to wildlife management authorities have proved to be native frogs (S. Crocetti [DECCW], pers. comm. 2009; D. Woods [DEC], pers. comm. 2009). To reduce this error rate, some community groups have tried to educate the public by means of brochures or websites (e.g., KTB, 2009; White and Shine, 2009) as well as mass media interventions (TV programs and documentaries e.g., Lewis, 1988). The effectiveness of such programs has not been evaluated. A belief in their ability to distinguish between cane toads and native frogs is widespread in the general community. We conducted a questionnaire-based study to quantify the ability of the general public to distinguish native frogs from cane toads, and the degree to which that ability is affected by attributes of the anuran (species, life-history stage) and the person (age, sex, domicile, profession, prior training). In a separate effort, we also surveyed community groups and wildlife authorities, as well as published literature, to ask which native anuran species had been reported to those organizations as "cane toads".

2. Materials and methods

2.1. Surveys of the general public

Our surveys took place in Darwin in the Northern Territory of Australia at the Mindel Sunset market (3 and 6 September 2009), Casuarina Square Shopping Mall (5 September 2009), Humpty Doo Shopping Centre (7 September 2009) and Mitchell Centre (8 September 2009). We exhibited live anurans in separate well-illuminated 30 × 20 × 20 cm glass terraria, and also used 25 × 20 cm color photographs (close-ups, taken from the side) in the case of tadpoles (of marbled frogs [*Limnodynastes convexiusculus*] and cane toads [*B. marinus*]) and egg clutches (of cane toads and rocket frogs [*Litoria nasuta*]). The live animals comprised four frog species including both heavy-bodied (long-footed frog [*Cyclorana longipes*], snout-vent length [SVL] = 53 mm; giant burrowing frog [*Cyclorana australis*], SVL = 92 mm) and slender-bodied (rocket frog, SVL = 47 mm; marbled frog, SVL = 56 mm; pale frog [*Litoria pallida*], SVL = 26 mm) species. The cane toads on display comprised an adult male (SVL = 106 mm), a subadult female (SVL = 68 mm), and metamorphs (average SVL = 19 mm). The native frogs and toads overlapped in size, although the toad metamorphs were smaller, and the adult male toad larger, than any of the native frogs.

Toads and native frogs were collected from the Adelaide River floodplain (12°28′S, 130°51′E) the night prior to the first survey. Terraria were mesh-topped, and contained a soil substrate with leaf litter, and access to water. Food (five crickets) was provided twice a day. Terraria were misted to maintain high humidity. The tanks were positioned on a table in a well-lit area such that passers-by could view each specimen from about a half a meter. Verbal consent was obtained from subjects before their participation, and potential subjects were handed a single page questionnaire (see Table 1). The questionnaire elicited information about the participant (age category, sex, profession, domicile, prior experience with toad-awareness sessions or toad-control groups) and asked people to nominate which animals (or photographs) they thought were cane toads rather than native frogs. After the survey was completed, we explained the correct answers and how best to distinguish between cane toads and native frogs. After completion of the study, native frogs were released at their point of capture; toads were returned to the University of Sydney Tropical Ecology Research Facility for further studies.

2.2. Surveys of wildlife management authorities and community groups

We contacted representatives of government agencies and toad-related community groups from across Australia to ask which native anurans, if any, had been brought in by members of the general public in the mistaken belief that these animals were cane toads. Our aim was to identify the taxa (especially, those of conservation concern) most likely to be victims of "friendly fire".

2.3. Statistical analyses

We analyzed the survey data using the statistical programs Statview 5.0 (SAS, 1998) and JMP 7.0 (SAS, 2007). Prior to analysis,

Table 1
Questionnaire used to obtain information on the ability of the general public to distinguish between cane toads and native frogs.

Questionnaire used to obtain information on the ability of the general public to distinguish between cane toads and native frogs.

Telling apart a Toad from a Frog

Age	10-15 ☐	26-35 ☐	46-55 ☐	66-75 ☐
	16-25 ☐	36-45 ☐	56-65 ☐	>76 ☐

Sex	Male ☐	Female ☐
Are you a	Resident in NT	☐
	Australian tourist	☐ State : QLD / NSW / VIC / SA / WA / TAS / ACT
	International tourist	☐ Country : ______________________________
Have you ever attended an awareness program on identifying cane toads?	Yes ☐	No ☐
Are you a member of a toad control community group?	Yes ☐	No ☐

Profession	Agriculture related work	☐	Publication related work	☐
	Construction related work	☐	Restaurant/ Hotel/ Pub	☐
	Diplomat	☐	School student	☐
	Driver	☐	Teacher/ Uni Lecturer	☐
	Fisherman	☐	Scientist	☐
	Health related work	☐	Sport related work	☐
	Journalists	☐	University student	☐
	Mining	☐	Wildlife officer/ Ranger	☐
	Political professionals	☐	Other	☐

Which ones are the adult or subadult toads? (there may be more than one)	A ☐	B ☐	C ☐	D ☐	E ☐	F ☐
Which are the baby toads?	G ☐	H ☐				
Which are toad tadpoles?	I ☐	J ☐				
Which are toad eggs?	K ☐	L ☐				

data were examined for normality, and data on proportions were square-root-transformed to achieve normality. Multicollinearity among predictor variables for respondent attributes (e.g., age, profession, and domicile were significantly intercorrelated) confounded interpretation of any tests on the survey data that did not consider multiple predictor variables simultaneously, so we included all of these variables (age, sex, profession, domicile [within the toad's Australian range or not], membership of a "toad-busting" group, and prior participation in an awareness course) as independent variables in a single ANOVA with square-root-transformed % error in identification as the dependent variable. We calculated three measures of overall accuracy of identification:

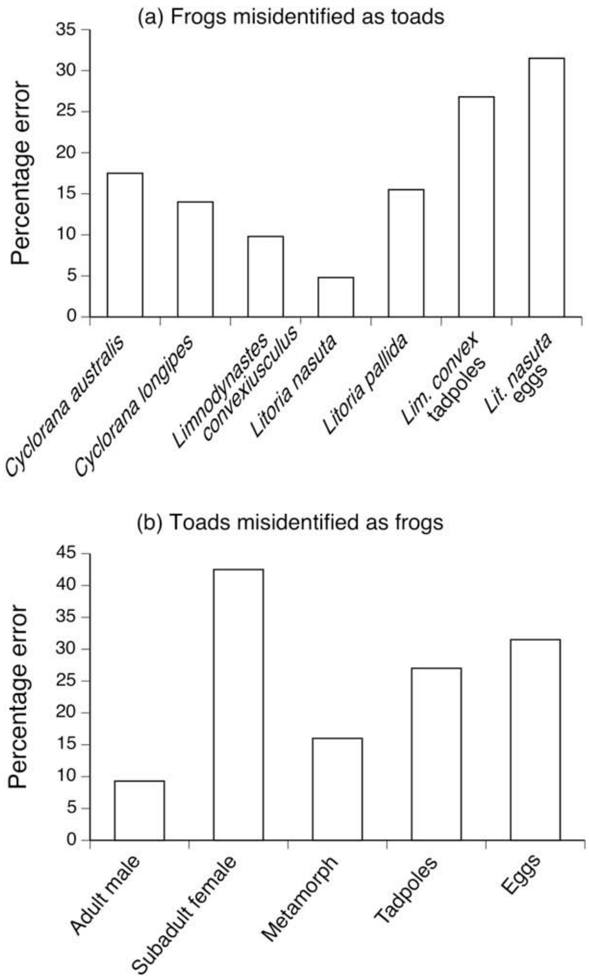

Fig. 1. The rate at which members of the general public misidentified anurans, divided into two types of error: (a) native frogs that were incorrectly thought to be invasive cane toads; and (b) cane toads that were incorrectly thought to be native frogs.

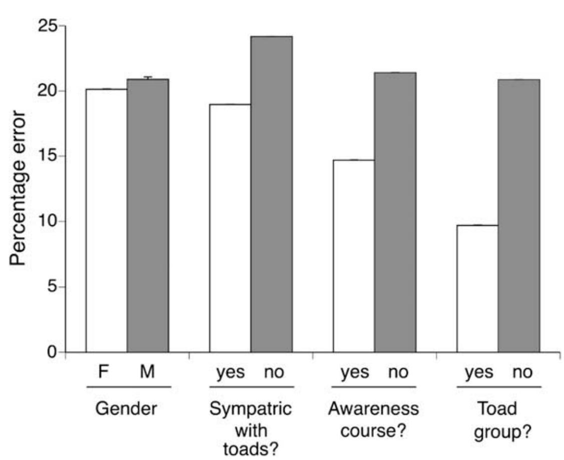

Fig. 2. The influence of respondent attributes on rates at which members of the general public failed in their attempts to distinguish between native frogs and invasive cane toads. The categories along the *X* axis refer to the sex of respondents, whether or not they lived in areas occupied by cane toads in Australia, whether or not they had previously taken a toad awareness (identification) course, and whether or not they belonged to a "toad-busting" community group.

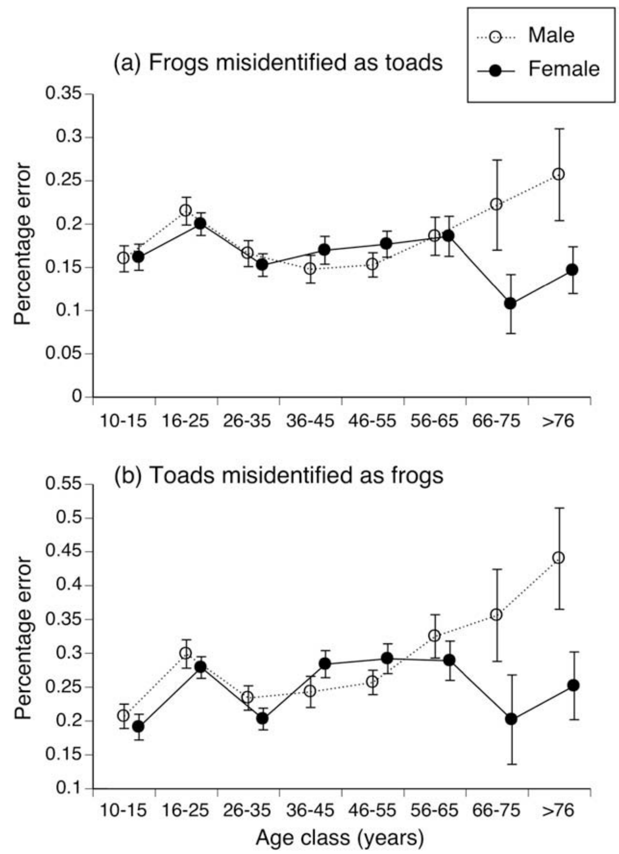

Fig. 3. The influence of respondent age and sex on rates at which members of the general public failed in their attempts to distinguish between native frogs and invasive cane toads.

the proportion of cases in which a person wrongly identified a native frog as a cane toad (out of seven questions); the proportion of cases in which he/she wrongly identified a cane toad as a native frog (out of five questions); and the overall proportion of errors (out of 13 questions). We initially separated these first two categories because the most critical kind of error for "friendly fire" against native frogs is the first category (i.e., a native frog that is thought to be a toad), and thus we wanted to check how highly the two types of error were correlated. We used contingency-table tests to compare overall accuracy of identification of different anurans presented in the survey. We also tabulated the anuran species reported as "cane toads" by members of the general public who brought these animals to the attention of wildlife authorities or community groups.

3. Results

3.1. Attributes of respondents

We obtained responses from 1328 people over 5 days of surveys, approximately equally divided by sex (47% male), and spanning age classes 10–15 through to >76 years of age. The median age class was 16–25 years, and most participants (89%) were between 10 and 55 years of age. Most (63%) were residents of the Northern Territory, with a wide scattering from other states in Australia, and 170 (13%) were international visitors. Only 43 people (3%) belonged to toad-control groups, whereas 177 (13%; including 28 of the 43 people who were members of a toad-busting group) had taken a toad-awareness course. Many professions were represented, of which the most common were school students ($n = 279$), construction workers ($n = 101$), health professionals ($n = 95$), and agricultural workers ($n = 90$).

Table 2
Native frog species reported as "cane toads" by members of the public. These are animals brought into authorities for destruction, in the mistaken belief that the animal involved was a cane toad.

Family and species[a]	Common name[a]	Stage confused	Status[a]	Distribution[a]	Source
Hylidae					
Cyclorana australis	Giant frog	Adults	Secure	WA, NT, QLD	NT PWS, 2009[b]; DEC, 2009[c]; Tyler and Knight, 2009
Cyclorana longipes	Long-footed frog	Adults	Secure	WA, NT, QLD	DEC, 2009
Cyclorana novaehollandiae	Wide-mouthed frog	Adults	Secure	QLD, NSW	Tyler and Knight, 2009; NQ Dry Tropics NRM, 2009
Litoria caerulea	Green tree frog	Adults; tadpoles	Secure	WA, NT, QLD, NSW, SA	DECCW, 2009[d]; FrogWatch, 2009
Litoria dentata	Keferstein's tree frog	Adults	Secure	QLD, NSW	DECCW, 2009
Litoria fallax	Eastern dwarf tree frog	Adults	Secure	QLD, NSW	DECCW, 2009
Litoria freycineti	Freycinet's frog	Adults	Secure	QLD, NSW	DECCW, 2009
Litoria inermis	Peter's frog	Adults	Secure	WA, NT, QLD	DEC, 2009
Litoria latopalmata	Broad-palmed frog	Adults	Secure	QLD, NSW, SA	DECCW, 2009
Litoria lesueurii	Lesueur's frog	Adults	Secure	NSW, VIC	DECCW, 2009
Litoria meiriana	Rockhole frog	Adults	Secure	WA, NT	DEC, 2009
Litoria nasuta	Rocket frog	Adults	Secure	WA, NT, QLD, NSW	DECCW, 2009
Litoria peronii	Peron's tree frog	Adults	Secure	QLD, NSW, VIC	DECCW, 2009
Litoria revelata	Whirring tree frog	Adults	Probably secure	QLD, NSW	DECCW, 2009
Litoria rubella	Red tree frog	Adult	Secure	WA, NT, QLD, NSW, SA	DEC, 2009
Litoria tyleri	Tyler's tree frog	Adults	Secure	QLD, NSW	DECCW, 2009
Litoria verreauxii verreauxii	Verreaux's tree frog	Adults	Probably secure	QLD, NSW, VIC	DECCW, 2009
Limnodynastidae					
Adelotus brevis	Tusked frog	Adults	Endangered	QLD, NSW	DECCW, 2009
Heleioporus australiacus	Giant burrowing frog	Adults	Vulnerable	NSW, VIC	Griffiths, 1997; DECCW, 2009
Lechriodus fletcheri	Fletcher's frog	Adults	Secure	QLD, NSW	DECCW, 2009
Limnodynastes convexiusculus	Marbled frog	Adults; tadpoles	Secure	WA, NT, QLD	NT PWS, 2009; DEC, 2009; FrogWatch, 2009
Limnodynastes dumerilii	Eastern banjo frog	Adults	Secure	QLD, NSW, VIC, SA, TAS	Griffiths, 1997; DECCW, 2009
Limnodynastes peronii	Striped marsh frog	Adults	Secure	QLD, NSW, VIC, SA, TAS	DECCW, 2009
Limnodynastes tasmaniensis	Spotted grass frog	Adults	Secure	QLD, NSW, VIC, SA, TAS	DECCW, 2009
Limnodynastes terraereginae	Northern banjo frog	Adults	Secure	QLD, NSW	DECCW, 2009
Neobatrochus pictus	Painted frog	Adults	Secure	NSW, VIC, SA	Griffiths, 1997; DECCW, 2009
Notaden melanoscaphus	Northern spadefoot frog	Adults	Secure	WA, NT, QLD	NT PWS, 2009
Platyplectrum ornatum	Ornate burrowing frog	Adults	Secure	WA, NT, QLD, NSW	NT PWS, 2009; DEC, 2009; DECCW, 2009
Myobatrachidae					
Crinia signifera	Common froglet	Adults	Secure	QLD, NSW, VIC, SA, TAS	DECCW, 2009
Crinia tinnula	Tinkling froglet	Adults	Secure	QLD, NSW	DECCW, 2009
Mixophyes fasciolatus	Great barred frog	Adults	Secure	QLD, NSW	DECCW, 2009
Mixophyes iteratus	Southern barred frog	Adults	Endangered	QLD, NSW	DECCW, 2009
Pseudophryne bibronii	Bibron's toadlet	Adults	Vulnerable	QLD, NSW, VIC, SA	DECCW, 2009
Uperoleia laevigata	Smooth toadlet	Adults	Secure	QLD, NSW, VIC	DECCW, 2009
Uperoleia lithomoda	Stonemason's toadlet	Adults	Secure	WA, NT, QLD	DEC, 2009
Uperoleia rugosa	Wrinkled toadlet	Adults	Secure	QLD, NSW	DECCW, 2009

[a] Following Tyler and Knight, 2009.
[b] NT PWS (Parks and Wildlife Services of the Northern Territory, 2009).
[c] DEC (Department of Environment and Conservation in Western Australia, 2009).
[d] DECCW (Department of Environment, Climate Change and Water in New South Wales, 2009).

3.2. Influence of anuran attributes on misidentification rates

Overall, respondents misidentified toads as native frogs 25.3% of the time, and native frogs as toads 17.1% of the time (so in total, error rate = 20.5%). The misidentification rate varied among taxa (contingency-table $\chi^2 = 487.96$, df = 6, $p < 0.0001$ for native frogs misidentified as toads, and $\chi^2 = 480.42$, df = 4, $p < 0.0001$ for toads misidentified as native frogs). For both toads and native frogs, error rates were high for eggs and tadpoles (around 30%; Fig. 1). Among terrestrial-phase native frogs, the most accurate identifications were of slender-bodied, long-limbed rocket frogs (4.8% error) and brightly patterned marbled frogs (error of 9.8%). Among toads, a large adult male was identified more accurately (9.3% error) than a subadult female (42.5% error; Fig. 1).

3.3. Influence of respondent attributes on misidentification rates

People who misidentified native frogs as toads also were more likely to misidentify toads as native frogs (linear regression: $r^2 = 0.49$, $p < 0.0001$). Because these two types of errors were highly correlated, we examine only overall (summed) error rates below. Misidentification rates were significantly affected by respondent age ($F_{7,1291} = 2.47$, $p < 0.017$), domicile ($F_{1,1291} = 15.09$, $p < 0.001$), prior participation in a toad-awareness course ($F_{1,1291} = 8.16$,

$p < 0.005$), membership of a toad-busting group ($F_{1,1291} = 8.56$, $p < 0.005$) and profession ($F_{18,1291} = 2.15$, $p < 0.005$). Of the factors we tested, only sex ($F_{1,1291} = 1.20$, $p > 0.25$) did not have a significant effect on error rates (see Figs. 2 and 3 for directions and sizes of these effects).

Although statistically significant, some of these effects were numerically small. For example, overall error rates among age classes ranged from 15% to 22%, tending to increase in older men but not women (Fig. 3). Prior experience at a toad-awareness class reduced error rates from 21% to 15%, and membership of a toad-busting group was associated with a decrease from 21% to 10%. Dividing Australian residents into people from the Northern Territory and Queensland (i.e., likely to have encountered cane toads) *versus* those from other states, the people from toad-infested areas had lower error rates (19% versus 24%; one-factor ANOVA, $F_{1,1326} = 26.27$, $p < 0.0001$). International visitors had relatively high error rates (24%), that were similar across the 11 overseas countries represented by two or more respondents ($F_{10,72} = 0.74$, $p = 0.69$).

3.4. Surveys of wildlife management authorities and community groups

In combination with published literature, our survey of representatives from wildlife management authorities and community groups across Australia confirms that mistakes in anuran identification are widespread (Table 2). A morphologically diverse array that includes 36 species of native frogs has been misidentified as cane toads, in many parts of the continent. Some of the taxa in Table 2 are of conservation concern with two species, the tusked frog (*Adelotus brevis*) and the southern barred frog (*Mixophyes iteratus*), listed as endangered (Tyler and Knight, 2009).

4. Discussion

The idea that it is environmentally responsible to kill cane toads is widespread in the Australian community, and has been enthusiastically promulgated by politicians, newspapers, and community leaders across the cane toads' Australian range (e.g., Anonymous, 2005, 2008; Cunningham, 2008). We are not the first to point out that this enthusiasm may have negative consequences for native frogs, if the general public finds it difficult to distinguish between bufonids and other anurans. There is abundant evidence that anti-toad publicity has resulted in the destruction of native frogs (e.g., Taylor and Edwards, 2005; Cordingley, 2009), even in parts of Australia well outside the current range of toads and hence, where most putative "toads" are likely to be native frogs (Field, 2004; Peacock, 2007; White, 2007; S. Crocetti [DECCW], pers. comm. 2009; R. Shine, unpubl. data).

Ideally, we would evaluate collateral impacts of "toad-busting" activities directly (by identifying animals collected by volunteer toad-killers), but in practice there are great logistical obstacles to this approach. Much of the mortality occurs sporadically, in the course of people's day-to-day activities; indeed, the more planning involved (as in communal "toad-busts"), the less likely there will be frequent misidentification. Hence, we can only attempt to evaluate: (a) the frequency of toad-killing and (b) the incidence of misidentification that could result in collateral mortality of native frogs. The product of these two rates will predict total frog mortality, but there are few quantitative data available on either topic. Toad-busting groups publish counts of their kills (in the hundreds of thousands: e.g., Peacock, 2007; STTF, 2009; Tyler and Knight, 2009) but as noted above, well-organized community-level activities are the least likely to result in inadvertent killing of native frogs. Many individual citizens also try to kill toads whenever they encounter them: for example, more than two-thirds of people interviewed in Darwin (including national and international tourists as well as Northern Territory residents) say they intentionally run over toads if they see them on the road (questionnaire survey by C. Beckmann, pers. comm.). Quantifying total rates of such mortality (and whether or not such mortality is intentional) is impossible, although it is clear that vast numbers of native frogs as well as toads are killed on roads in the Darwin area (R. Somaweera, pers. obs.).

Our results are sobering, in that approximately 20% of native frogs were misidentified as cane toads even under circumstances more amenable to careful identification than would normally be the case in the field. For example, people deliberately running "toads" over at night on highways would have far more difficulty distinguishing a toad from a native frog than was the case in the current study. We provided a well-lit room, anurans in clear view, the opportunity to compare one species to another, and provided the information that the group of animals included at least one toad and at least one native frog. Even under these circumstances, mistakes were frequent. For example, 43% of respondents identified a subadult toad as a native frog, and more than 30% identified rocket frog eggs as toad eggs. Although the accuracy of identification was affected by attributes both of the anuran and of the person attempting to identify it, such effects were relatively small. For most combinations that we evaluated, around 20% of identifications were erroneous (Figs. 1–3). Thus, although error rates were lower for NT residents than international visitors (whose toad-killing activities likely would be restricted to a brief period during their visit), the difference in error rates was small enough to have little overall impact.

Whether or not this error rate translates into mortality of native frogs will depend upon the nature of toad-killing activities. Well-organized community groups who sponsor communal toad-busting activities ensure that trained members check anuran identifications before any animals are killed. The same is true of government authorities who encourage public collection of toads, but ask that the animals be brought in alive so that their identity can be verified (e.g., S. Crocetti [DECCW], pers. comm. 2009; D. Woods [DEC], pers. comm. 2009). Frogs can then be released, although their viability might be reduced (e.g., by injury sustained during capture or transport, disease transfer, or release at an unsuitable site [as shown for other animals e.g., Cunningham, 1996; Robertson and Harris, 1995; Herr et al., 2008]). More problematic are citizens who undertake personal vendettas against cane toads, especially if the killing is done in circumstances that do not allow close inspection of the intended victim prior to dispatch (e.g., by motor vehicle, spraying of poison, etc.; Taylor and Edwards, 2005).

Unintentional killing of native frogs during "toad-busting" activities by private citizens poses both ethical and ecological issues. Our own opinion is that cane toads deserve the same ethical treatment as do native frogs, but this is a minority view within Australian society (White, 2007). Although community groups insist that toads are killed humanely, some sections of the public believe that invasive species deserve no such compassion. For example, one politician posed with a golf club and a cane toad for the front page of an Australian newspaper, encouraging citizens to kill as many toads as possible in any way that they fancied (Anonymous, 2005). Although many Australians would be appalled at inhumane treatment of native frogs, cane toads attract less concern. Such attitudes are expressed towards many invasive animal species (reviewed by Littin et al., 2004; but see Bremner and Park, 2007). Hence, native frogs killed as a result of mistaken identity may be treated less kindly in that process than would be the case if their true identity was known.

On an ecological level, what are the likely consequences of "friendly fire" directed towards native frogs? Any unanticipated negative effect from killing native frogs needs to be balanced against positive outcomes from reducing toad abundances. Unfortunately, the ecological benefits of toad removal are unclear. The only well-documented mechanism of ecological impact of cane toads in Australia involves mortality of predators through lethal ingestion of the highly toxic toads (Griffiths and McKay, 2007; Phillips et al., 2007; Letnic et al., 2008; Shine, 2010), sometimes resulting in secondary positive effects for the predators' usual prey (Doody et al., 2006). Such effects happen as soon as toads invade an area; reducing toad densities at a later date may do little to reduce overall impacts, although lower toad densities ultimately might facilitate predator recovery. A reduction in toad numbers may ameliorate the intensity of competition between toads and native frogs, and reduce predation by toads – but these processes may not pose major challenges to the fauna of toad-infested areas (Greenlees et al., 2007; Pearson et al., 2009).

Similar uncertainties arise about negative ecological impacts of "friendly fire" (i.e., inadvertent killing of native frogs). Many amphibian species can attain high densities, but only a small proportion of the population is catchable on any given night due to low detection probabilities (Pellet and Schmidt, 2005; Smith et al., 2006). Thus, hand-collecting and trapping are unlikely to have major impacts on native frog (or toad) densities in many areas. High recruitment rates also can buffer any anthropogenic effects. Unfortunately, many native frog species are declining in abundance worldwide (Blaustein and Kiesecker, 2002; Stuart et al., 2004; Rohr et al., 2008), and an additional mortality source could threaten the viability of some local populations, or even of species with small distribution ranges. Clearly, education efforts should be framed to help people recognize locally rare species, especially large-bodied taxa that typically occur at low densities, and are the most likely to be mistaken for cane toads (e.g., *Heleioporus*, *Mixophyes*; Table 2).

Lastly, what do our results imply for toad-killing efforts by the general public? We doubt that "friendly fire" is a significant issue in the case of well-organized "toad-busts" conducted by community groups and wildlife authorities, because such events have systems in place to assure identification of anurans before they are killed. In contrast, opportunistic killing of toads by local citizens may incur higher risks of inadvertent mortality of native frogs, especially if the methods used preclude careful identification of the anuran prior to its dispatch. The highest rates of collateral damage will occur in areas where toads are scarce but native frogs are common, such as places outside the main range of the toad. Private citizens living in such areas should be discouraged from routinely destroying any anuran suspected of being a cane toad, because in many such cases the likely victim will be a native frog rather than an invasive toad.

More generally, there may be many situations where untrained members of the general public have difficulty distinguishing between different species of plants or animals. The lack of native bufonids in Australia, coupled with the much larger body size and distinctive morphology of cane toads compared to native frogs, suggest that error rates in identifying cane toads will be lower than in many other situations. Especially if the species in question is seen in conditions where close observation is difficult (e.g., an animal fleeing from the observer, or seen in dim light at long distance), reliability of identification cannot be assumed. Accordingly, conservation initiatives that rely upon the general public's ability to distinguish feral pests from native species should carefully consider the likely magnitude of any errors, and the consequences of such errors for animal welfare as well as for conservation aims. Our results are encouraging in that prior identification training and membership of community groups reduced error rates in toad identification (Fig. 2), but relatively high overall rates of misidentification leave little room for complacency.

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References

Anonymous, 2005. Whacking day: MP urges public to kill cane toads. Sydney Morning Herald (11 April).
Anonymous, 2008. 'Kill a toad' day. Sydney Morning Herald (4 April).
Baskin, Y., 2002. A Plague of Rats and Rubbervines: The Growing Threat of Species Invasion. Island Press, Washington DC.
Blaustein, A.R., Kiesecker, J.M., 2002. Complexity in conservation: lessons from the global decline of amphibian populations. Ecology Letters 5, 597–608.
Bremner, A., Park, K., 2007. Public attitudes to the management of invasive non-native species in Scotland. Biological Conservation 139, 306–314.
Bright, C., 1998. Life Out of Bounds: Bioinvasion in a Borderless World. W.W. Norton, New York.
Ceballos, C.P., Fitzgerald, L.A., 2004. The trade in native and exotic turtles in Texas. Wildlife Society Bulletin 32 (3), 881–892.
Chew, M.K., Laubichler, M.D., 2003. Natural enemies – metaphor or misconception? Science 301, 52–53.
Corbett, S.W., Anderson, B., Nelson, B., Bush, S., Hayes, W.K., Cardwell, M.D., 2005. Most lay people can correctly identify indigenous venomous snakes. The American Journal of Emergency Medicine 23 (6), 759–762.
Cordingley, G., 2009. Mistaken identity. The Sunday Times (22 March).
Cousins, J.A., Sadler, J.P., Evans, J., 2008. Exploring the role of private wildlife ranching as a conservation tool in South Africa: Stakeholder perspectives. Ecology and Society 13 (2), 43. <http://www.ecologyandsociety.org/vol13/iss2/art43/> (accessed 07.02.09).
Cunningham, A.A., 1996. Disease risks of wildlife translocations. Conservation Biology 10, 349–353.
Cunningham, M., 2008. Don't be a fool, kill as many cane toads as you can: Lord Mayor. Northern Territory News (18 August).
Decker, S.E., Bath, A.J., Simms, A., Lindner, U., Reisinger, E., 2010. The return of the king or bringing snails to the garden? The human dimensions of a proposed restoration of European Bison (*Bison bonasus*) in Germany. Restoration Ecology 18 (1), 41–51.
Doody, J.S., Green, B., Sims, R., Rhind, D., West, P., Steer, D., 2006. Indirect impacts of invasive cane toads (*Bufo marinus*) on nest predation in pignosed turtles (*Carettochelys insculpta*). Wildlife Research 33, 49–54.
Field, K., 2004. Native frogs victims of cane toad cull. AAP General News (Australia) (11 November).
FrogWatch, 2009. Cane toad tadpole identification fact sheet. <http://www.frogwatch.org.au/digitalLibrary/file_store/49A858F4-C09F-44B0-F14B7DB700-564F60.pdf> (accessed 12.09.09).
Genet, K.S., Sargent, L.G., 2003. Evaluation of methods and data quality from a volunteer-based amphibian call survey. Wildlife Society Bulletin 31 (3), 703–714.
Gong, S.P., Chow, A.T., Fong, J.J., Shi, H.T., 2009. The chelonian trade in the largest pet market in China: scale, scope and impact on turtle conservation. Oryx 43 (2), 213–216.
Greenlees, M.J., Brown, G.P., Webb, J.K., Phillips, B.L., Shine, R., 2007. Do invasive cane toads (*Chaunus marinus*) compete with Australian frogs (*Cyclorana australis*)? Austral Ecology 32, 900–907.
Griffiths, K., 1997. Frogs and Reptiles of the Sydney Region. University of New South Wales Press, Sydney.
Griffiths, A.D., McKay, J.L., 2007. Cane toads reduce the abundance and site occupancy of Merten's water monitor (*Varanus mertensi*). Wildlife Research 34, 609–615.
Hagman, M., Hayes, R.A., Capon, R.J., Shine, R., 2009. Alarm cues experienced by cane toad tadpoles affect post-metamorphic morphology and chemical defences. Functional Ecology 23, 126–132.
Henderson, W.R., Murphy, E.C., 2007. Pest or prized possession? Genetically modified biocontrol from an international perspective. Wildlife Research 34, 578–585.
Herr, J., Schley, L., Roper, T.J., 2008. Fate of translocated wild-caught and captive-reared stone martens (*Martes foina*). European Journal of Wildlife Research 54, 511–514.
KTB (Kimberley Toad Busters), 2009. Is it a native frog or cane toad? <http://www.canetoads.com.au/toadfrog.htm> (accessed 30.09.09).
Larson, B.M.H., 2005. The war of the roses: demilitarizing invasion biology. Frontiers in Ecology and the Environment 3, 495–500.

Lepczyk, C.A., Mertig, A.G., Liu, J., 2003. Landowners and cat predation across rural-to-urban landscapes. Biological Conservation 115, 191–201.

Letnic, M., Webb, J.K., Shine, R., 2008. Invasive cane toads (*Bufo marinus*) cause mass mortality of freshwater crocodiles (*Crocodylus johnstoni*) in tropical Australia. Biological Conservation 141, 1773–1782.

Lever, C., 2001. The Cane Toad. The History and Ecology of a Successful Colonist. Westbury Scientific Publishing, Otley, West Yorkshire.

Lewis, M., 1988. Cane Toads: An Unnatural History. Film Australia, Lindfield, NSW (video recording).

Lippman, T.W., 1991. Instances of friendly fire are not surprising on the battlefield. The Washington Post, 3 February, p. A-23.

Littin, K.E., Mellor, D.J., Warburton, B., Eason, C.T., 2004. Animal welfare and ethical issues relevant to the humane control of vertebrate pests. New Zealand Veterinary Journal 52, 1–10.

Lloyd, S., 2006. A miner concern – birdwatching on the east coast. Newsletter of the Land for Wildlife Scheme Tasmania 11, 4–5.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., Bazzaz, F.A., 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10, 689–710.

MacLeod, A., Evans, H.F., Baker, R.H.A., 2002. An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) in the European community. Crop Protection 21, 635–645.

Maki, K., Galatowitsch, S., 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. Biological Conservation 118, 389–396.

Mid North Coast Indian Myna Project. 2009. Indian Myna: Managing the Invasion of Indian Mynas on the NSW Mid North Coast. <http://www.coffsharbour.nsw.gov.au/resources/documents/Myna_DLFlyer_V6_sized.pdf> (accessed 07.02.10).

Morrison, J.J., Pearn, J.H., et al., 1983. Can Australians identify snakes? Medical Journal of Australia 2, 66–70.

Northern Australian Frogs Database System, 2009. ToadBusters. <http://www.frogwatch.org.au/index.cfm?fuseaction=toadbusters> (accessed 12.07.09).

NQ Dry Tropics NRM (North Queensland Dry Tropics Natural Resources Management), 2009. Native frog or cane toad? <http://www.frogsnotcanetoads.com.au/template.php?page=cyclorananovaehollandiae> (accessed 15.09.09).

Peacock, T., 2007. Community on-ground cane toad control in the Kimberley. A review conducted for the Hon. David Templeman MP, Minister for the Environment, Climate Change and Peel. Department of Environment and Conservation, and Invasive Animals CRC, Canberra.

Pearson, D.J., Greenlees, M., Ward-Fear, G., Shine, R., 2009. Predicting the ecological impact of cane toads (*Bufo marinus*) on threatened camaenid land snails in north-western Australia. Wildlife Research 36, 533–540.

Pellet, J., Schmidt, B.R., 2005. Monitoring distributions using call surveys: estimating site occupancy, detection probabilities and inferring absence. Biological Conservation 123, 27–35.

Phillips, B.L., Brown, G.P., Shine, R., 2003. Assessing the potential impact of cane toads on Australian snakes. Conservation Biology 17, 1738–1747.

Phillips, B.L., Brown, G.P., Greenlees, M., Webb, J.K., Shine, R., 2007. Rapid expansion of the cane toad (*Bufo marinus*) invasion front in tropical Australia. Austral Ecology 32, 169–176.

Pramuk, J.B., Robertson, T., Sites Jr., J.W., Noonan, B.P., 2008. Around the world in 10 million years: biogeography of the nearly cosmopolitan true toads (Anura: Bufonidae). Global Ecology and Biogeography 17, 72–83.

Robertson, C.P.J., Harris, S., 1995. The condition and survival after release of captive-reared fox cubs. Animal Welfare 4, 281–294.

Rohr, J.R., Raffel, T.R., Romansic, J.M., McCallum, H., Hudson, P.J., 2008. Evaluating the links between climate, disease spread, and amphibian declines. Proceedings of the National Academy of Sciences of the United States of America 105, 17436–17441.

Sarver, M., Treher, A., Wilson, L., Naczj, R., Kuehn, F.B., 2008. Mistaken Identity. Invasive Plants and their Native Look-Alikes – An Identification Guide for the Mid-Atlantic. Delaware Dept of Agriculture.

SAS, 1998. Staview 5.0. SAS Institute, Cary, North Carolina.

SAS, 2007. JMP 7.0. SAS Institute, Cary, North Carolina.

Saunders, G., Cooke, B., McColl, K., Shine, R., Peacock, T., 2010. Modern approaches for the biological control of vertebrate pests: an Australian perspective. Biological Control 52, 288–295.

Schmetterling, D.A., Long, M.H., 1999. Montana Anglers' inability to identify Bull Trout and other Salmonids. Fisheries 24 (7), 24–27.

Shao, K.T., 2009. Marine biodiversity and fishery sustainability. Asia Pacific Journal of Clinical Nutrition 18 (4), 527–531.

Shine, R., 2009. Controlling cane toads ecologically. Australasian Science 1 (7), 20–23.

Shine, R., 2010. The ecological impact of invasive cane toads (*Bufo marinus*) in Australia. Quarterly Review of Biology, in press.

Shrader, C.R., 1982. Amicicide: the problem of friendly fire in modern war. Combat Studies Research Survey No. 1. US Army Command and General Staff College, Fort Leavenworth, Kansas.

Smith, J., Phillips, B., 2006. Toxic tucker: the potential impact of cane toads on Australian reptiles. Pacific Conservation Biology 12, 40–49.

Smith, L.L., Barichivich, W.J., Staiger, J.S., Smith, K.G., Dodd, C.K., 2006. Detection probabilities and site occupancy estimates for amphibians at Okefenokee National Wildlife Refuge. American Midland Naturalist 155, 149–161.

Stelfox, J.D., Shumaker, G.E., Baayens, D.M. 2001. Fish identification education. In: Brewin, M.K., A.J. Paul, A.J., Monita, M. (Eds.), Bull Trout II Conference Proceedings, Trout Unlimited Canada, Calgary, Alberta, pp. 63–66.

STTF (Stop the Toad Foundation), 2009. 2009 great toad muster report. <http://www.stopthetoad.org.au/publications/2009MusterReport.pdf> (accessed 05.02.09).

Stuart, S.N., Chanson, J.S., Cox, N.A., Young, B.E., Rodrigues, A.S.L., Fischman, D.L., Waller, R.W., 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306, 1783–1786.

Taylor, R., Edwards, G., 2005. A review of the impact and control of cane toads in Australia with recommendations for future research and management approaches. Report to the Vertebrate Pests Committee from the National Cane Toad Task Force, July 2005.

Thresher, R.E., Bax, N., 2006. Comparative analysis of genetic options for controlling invasive populations of the cane toad *Bufo marinus*. In: Molloy, K.L., Henderson, W.R. (Eds.), Science of Cane Toad Invasion and Control. Proceedings of the Invasive Animals CRC/CSIRO/QLD NRM&W Cane Toad Workshop Brisbane, 5–6 June, pp. 117–122.

Tyler, M.J., Knight, F., 2009. Field Guide to the Frogs of Australia. CSIRO Publishing, Australia.

Venter, O., Brodeur, N.N., Nemiroff, L., Belland, B., Dolinsek, I.J., Grant, J.W.A., 2006. Threats to endangered species in Canada. BioScience 56 (11), 903–910.

Ward-Fear, G., Brown, G.P., Greenlees, M., Shine, R., 2009. Maladaptive traits in invasive species: in Australia, cane toads are more vulnerable to predatory ants than are native frogs. Functional Ecology 23, 559–568.

WetlandCare Australia, 2009. Fact Sheet: Indian Myna. <http://www.wetlandcare.com.au/docs/fact_sheets/myna_factsheet_final.pdf> (accessed 07.02.10).

Whelan, J., Lyons, K., 2005. Community engagement or community action: Choosing *not* to play the game. Environmental Politics 14 (5), 596–610.

White, A.W., 2007. Living with *Bufo*. In: Lunney, D., Eby, P., Hutchings, P., Burgin, S. (Eds.), Pest or Guest: The Zoology of Overabundance. Royal Zoological Society of New South Wales, Mosman, Sydney, pp. 16–29.

White, A.W., Shine, R., 2009. The extra-limital spread of an invasive species via "stowaway" dispersal: toad to nowhere? Animal Conservation 12, 38–45.

Wilson, B.C., Rohwer, F.C., 1995. In-hand duck identification by hunters at Mississippi flyway public hunting areas. Wildlife Society Bulletin 23 (3), 472–480.