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How safe is mist netting? evaluating the risk of injury and mortality to birds

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Summary

1. The capture of birds using mist nets is a widely utilized technique for monitoring avian populations. While the method is assumed to be safe, very few studies have addressed how frequently injuries and mortalities occur and the associated risks have not been formally evaluated.

2. We quantified the rates of mortality and injury at 22 banding organizations in the United States and Canada and used capture data from five organizations to determine what kinds of incidents occur most frequently. Analyses focused on passerines and near-passerines, but other groups were included. We evaluated whether body mass, age, sex, mist net mesh size, month and time of day or frequency of capture are related to the risk or type of incident. We also compared the recapture histories over time between birds that were injured and those that were never injured for 16 species.

3. The average rate of injury was 0·59%, while mortality was 0·23%. Birds captured frequently were less at risk to incident. Body mass was positively correlated with incident and larger birds were at greater risk to predation, leg injuries, broken legs, internal bleeding and cuts, while smaller birds were more prone to stress, tangling-related injuries and wing strain. Rates of incident varied among species, with some at greater risk than others. We found no evidence for increased mortality over time of injured birds compared with uninjured birds.

4. We provide the first comprehensive evaluation of the risks associated with mist netting. Our results indicate that (1) injury and mortality rates below one percent can be achieved during mist netting and (2) injured birds are likely to survive in comparable numbers to uninjured birds after release. While overall risks are low, this study identified vulnerable species and traits that may increase a bird's susceptibility to incident that should be considered in banding protocols aimed at minimizing injury and mortality. Projects using mist nets should monitor their performance and compare their results to those of other organizations.

Key-words: avian, banding, injury, mist netting, mortality rate, research techniques, ringing, wildlife capture

Introduction

Wildlife research often requires that animals be captured and handled to monitor populations, collect morphometric data, attach devices or record life-history characteristics. While researchers often assume that the benefits of information gained outweigh the potential risk to individual animals, the impacts are not always quantified (Wilson & McMahon 2006).

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Some methods such as blood and diet sampling in birds (Carlisle & Holberton 2006; Brown & Brown 2009; Voss, Shutler, & Werner 2010), branding and tagging in seals (McMahon, van den Hoff, & Burton 2005; Baker & Johanos 2006) and radiotelemetry in mammals and birds (Kock *et al.* 1987; Bailey *et al.* 1996; Del Giudice *et al.* 2005; Arnemo *et al.* 2006; Barron, Brawn, & Weatherhead 2010) have been scrutinized carefully to determine potential effects on survival, reproduction and behaviour, whereas other methods such as the use of mist nets to capture wild birds have rarely been evaluated (Wilson & McMahon 2006; Jennings *et al.* 2009). Procedures that affect the welfare of animals raise ethical considerations and can compromise research objectives by introducing bias into data collection and should be considered when interpreting results (Dugger *et al.* 2006; Wilson & McMahon 2006; Saraux *et al.* 2011). Furthermore, it is not possible to determine acceptable levels of risk for a research method until a proper evaluation of capture-related injuries and mortalities has been conducted (Wilson & McMahon 2006).

Mist netting is a commonly used technique for capturing birds to monitor demographic and population parameters. The few existing reports of incidents (hereafter, incident is used to refer either to an injury or to a mortality) associated with mist netting document rates of mortality ranging from 0·6 to 1·4% (Stamm, Davis, & Robbins 1960; Recher, Gowing, & Armstrong 1985; Brooks 2000). However, these reports are all from studies with limited geographic ranges and sample sizes that are considerably smaller than many long-running projects in the United States and Canada. Although over a million birds are banded in the United States alone every year (Bird Banding Laboratory 2010), to our knowledge, a systematic analysis of risks has never been conducted. The Handbook of Field Methods for Monitoring Landbirds (Ralph *et al.* 1993) provides a guideline of a 1% mortality rate, above which mortalities should be considered excessive. However, the recommendation in Ralph *et al.* (1993) is based on expert opinion, and it is unclear whether this rate is achievable in practice. Bird observatories and research programmes monitor bird populations using mist netting at hundreds of locations in the United States and Canada, many of which maintain detailed records of each mortality and injury that occur. These data provide an opportunity to establish a baseline against which all organizations can assess their performance.

When a bird is captured in a mist net, extrinsic factors such as human error during handling, time of year (e.g. breeding, migrating, or moulting birds) or time of day of capture (with increasing temperatures throughout the morning), predators and mist net mesh material and size can alter the likelihood of incident (North American Banding Council 2001). Mist netting projects typically capture a variety of resident and migratory species (Remsen & Good 1996), and it is likely that some species are more at risk to incident than others. Factors intrinsic to individual birds may also influence risk, and life stages with reduced survival rates such as post-juvenile dispersal may correspond to increased vulnerability during capture if periods of low survival correspond to poor body condition and increased stress.

In this study, we predicted that species, body size, age, sex and the timing of capture could influence the likelihood of an incident, and we predicted that birds released after an injury would survive in lower numbers compared to those released uninjured. First, we conducted a survey of bird observatories to quantify the rates of incident that are typical for a variety of organizations. Second, we quantified the most common types of injury and mortality, species with highest risk of incident, and whether body size, age, sex, mist net mesh size, number of captures, time of day or the month of capture influenced the risk or type of incidents commonly sustained. Finally, we evaluated whether recapture rates or histories were different for birds that were released after an injury relative to those that did not sustain injuries. We acknowledge that there are other factors such as daily fluctuations in weather and bander training and experience that could influence the rate of incident that we did not include in this study because we did not have access to these data. Despite this limitation, we have attempted to be as comprehensive as possible. Ultimately, our goal was to provide information that will allow banding organizations to assess their own performance and to improve protocols to reduce the frequency of capture-related incidents.

Methods

SURVEY OF ORGANIZATIONS

To establish baseline rates of injury and mortality, we requested information from 70 bird observatories and banding organizations listed on the BIRDNET (Ornithological Council) and the United States Geological Survey Bird Banding Laboratory (Patuxent Wildlife Research Center) websites. Organizations were contacted twice by e-mail in 2009. Each organization was asked to provide numbers of captured birds in their study, the duration of their activities and the number of birds that were injured or that died during mist netting operations.

DATA COLLECTION

All analyses beyond our initial survey are based on data from five organizations that volunteered to also contribute individual records of incidents. The complete data set contained a total of 345,752 captured birds over the reporting period. Portions of the data set were used for different analyses depending on the data that each organization chose to share. Fourteen species with fewer than 10 captures and no injuries or mortalities were eliminated because of small sample sizes. The remaining data set contains records from 188 species belonging to 31 families.

Contributing organizations included the San Francisco Bay Bird Observatory (SFBBO, $n = 23{,}995$ captures from 2001 to 2006), the Idaho Bird Observatory (IBO, $n = 73{,}792$ captures from 1997 to 2008), PRBO Conservation Science (formerly Point Reyes Bird Observatory, PRBO hereafter, $n = 111{,}921$ captures from 1988 to 2008 from stations located in Marin County, California), the Alaska Bird Observatory (ABO, $n = 69{,}262$ captures from 1992 to 2008) and the USDA Forest Service Pacific Southwest Research Station, Arcata Laboratory (formerly Redwood Sciences Laboratory, PSW Arcata hereafter), which included captures from collaborators at the Humboldt Bay Bird Observatory (PSW Arcata, $n = 66{,}782$ captures from 1999 to 2008).

All five organizations conduct mist netting for five or six hours beginning within 45 min of sunrise. The frequency of operation varies by organization: ABO operates from April to October either daily or every 5 days, IBO daily from July to October and PRBO, SFBBO and PSW Arcata operate year-round either 6 days a week, 3 days a week, once a week or once every 10 days depending on the banding station and season. All five organizations check mist nets for birds every 30 min with shorter intervals during periods of heat and cold and close nets during inclement weather and rain. All organizations use protocols for training banders taken from the North American Banding Council training manual (North American Banding Council 2001). SFBBO uses either nylon or polyester nets, while the remaining four organizations have used only nylon nets during the periods reported in this study. Mesh size also varies by organization; PSW Arcata uses only 36 mm, IBO uses 32 mm, PRBO uses both 30 and 36 mm and ABO and SFBBO use only 30 mm.

TYPES OF INCIDENT

We assessed the frequency of different types of incident by assigning a category and an outcome (injury or mortality) for each record. Assignments were obtained by reading the notes associated with the record that often contained information about the symptoms seen in the bird and any accidents that took place during capture or handling. In cases where two or more incidents were reported, we chose whichever was most likely to have been caused by the mist netting process. Injuries identified as unrelated to capture, such as avian pox or pre-existing deformities, were retained in the data set but categorized as uninjured birds. Each organization had its own conventions for reporting incidents, and within-organization reporting was not always consistent during the study period because of changes in personnel or protocol revisions. Our identification of the categories of injury is therefore imperfect, although we made an effort to standardize by identifying organization-specific conventions for referring to common injuries and creating categories that could be applied easily to all organizations.

Notes that reported either bleeding from the mouth (excluding tongue injuries) or a 'burst air sac' were categorized as internal injuries, and tongue injuries included cases when the bird's tongue was tangled in the net causing bleeding or obvious muscular strain. Broken bones were nearly always of the leg. Wing strain included birds that had either visibly strained or (rarely) dislocated wings or were unable to fly upon release. Stress was classified for birds that were panting or lethargic, closed their eyes during handling, raised feathers or were put in a box with or without heat to recover before release.

VULNERABLE SPECIES

To determine which species are most vulnerable to incident, we selected the 36 most commonly captured species each of which was represented in the data set by more than 2000 captures. We evaluated the relative probability of incident using a Generalized Linear Mixed Model (GLMM) with the logistic (incident = 1, no incident = 0) link function and a binomial error distribution fitted using Laplace approximation. We estimated parameters using maximum likelihood and the glmer function in the lme4 package in R 2.10.1 (R Development Core Team 2009) following recommendations in Bolker *et al.* (2008) and Zuur *et al.* (2009). GLMM allows the analysis of non-normally distributed data and the inclusion of random effects terms, which are useful for data sets with potential temporal and spatial autocorrelation (Crawley 2007). In our study, sampling locations and when birds were captured could not be controlled, but the spatial and temporal variability is potentially important.

We fit a single saturated model with species as a fixed effect and year and organization as random effects, which we compared to a reduced model without species using a likelihood ratio test (LRT). We included a year by organization interaction term because we anticipated that yearly differences that could affect the probability of incident might vary geographically. While the use of null hypothesis testing in observational studies has been criticized (see Burnham & Anderson 2002; Johnson & Omland 2004 among others), it can be appropriate when the primary objective is to determine whether a biologically meaningful difference between groups exists and when only a single hypothesis is being tested (Stephens *et al.* 2005). In GLMM, using LRT for fixed effects is reliable when sample sizes are large relative to the number of parameters (Bolker *et al.* 2008). In our case, we considered 305,534 records to be adequate for our saturated model, which contained 39 parameters.

INDIVIDUAL PREDICTORS OF RISK

To assess whether risk factors inherent to differences between individuals are related to the probability of incident, we analysed the data from PRBO alone. We used GLMM with covariates age, individual body mass (measured for each capture record), sex, capture number (the number of times the individual was captured), time of day, mesh size (30 or 36 mm) and month of capture as fixed effects and year, station (PRBO operates several in Marin County separated by up to 32 km), species, and species by year and year by station interaction terms as random effects. Capture number and body weight were continuous covariates, and mesh size, sex, month and age were categorical variables with two categories each for age (hatch year and after hatch year) and mesh size (30 and 36 mm). Whenever possible, age was determined by the degree of skull pneumatization or plumage criteria using the calendar year ageing system and sex was determined by breeding condition, plumage and rarely by morphometric data (Pyle 1997). Of the 111,921 captures in the PRBO data set, 69,414 individuals were captured between one and 44 times. Mist net mesh size is known to influence the size of birds that are captured most frequently (Pardieck & Waide 1992) and could be related to what types of birds are prone to incident.

We compared models using Akaike's Information Criteria (AIC) after identifying a candidate set of 53 models identified *a priori* following guidelines outlined in Burnham & Anderson (2002). Of the candidate models, ten contained all fixed effects terms and varying random effects terms. The remaining 43 models included combinations of extrinsic covariates (month, time of day and mesh size) and intrinsic factors (sex, age, capture number and individual mass) that we thought most likely to be important. We began by comparing all random effects models. Using the best fitting of these models, we then fitted all fixed effects models with the best possible combination of random effects following guidelines in Zuur *et al.* (2009). Model fit was assessed on the basis of low AIC and high AIC weight (w)(Burnham & Anderson 2002). We calculated importance weights ($w+$) for each covariate using the 95% confidence set of models, and we model averaged parameter estimates across top performing models.

BODY SIZE

To determine whether larger birds are affected by different kinds of incidents than smaller birds, we selected the eight most common categories in the complete data set (stress, predation, wing strain, broken bones, tangling, internal bleeding, leg injuries and cuts) and used

GLMM to quantify the relationship between body size and incident type. The saturated model included fixed effect covariates mass (as a measure of body size) and random effects species, organization, year, year by organization and species by organization interaction. Because we did not have the mass for individual birds for all five organizations, we used average species masses (hereafter species mass) taken from Sibley's Guide to Birds (Sibley 2003) and checked for accuracy against Duning's CRC Handbook of Avian Body Masses (Dunning 2008). We compared a fully saturated model to a single reduced model without species mass using LRT for each category of incident separately.

POST-INJURY RECAPTURES

To determine whether recapture rates were similar for injured and uninjured birds, we chose sixteen common species from the PRBO and IBO data sets (PRBO: Western Flycatcher, Chestnut-backed Chickadee, Ruby-crowned Kinglet, Swainson's Thrush, Hermit Thrush, Varied Thrush, Wrentit, Wilson's Warbler, Spotted Towhee, Song Sparrow, Golden-crowned Sparrow, and Dark-eyed (Oregon) Junco. IBO: Ruby-crowned Kinglet, MacGillivray's Warbler, Spotted Towhee, Chipping Sparrow, (Gambel's) White-crowned Sparrow, Dark-eyed (Oregon) Junco, Western Tanager). We chose species with both high numbers of recaptures and at least 30 records of injuries, and we included species with differing migratory habits (year-round resident, winter resident or summer resident) because recapture rates may not be the same for resident and migratory species. Mortalities were removed from the data set along with any captures that occurred before an injury. We calculated the number of days between the injury (for injured birds) or the initial capture (for uninjured birds) and each successive recapture at least one day from the first capture or injury to obtain the recapture history for each individual which were pooled into a mean for each species. To determine whether the rates of recapture and recapture histories over time were different for injured and uninjured birds, we used a student's paired, two-tailed *t*-test.

Results

SURVEY OF ORGANIZATIONS

Of 70 organizations contacted, 22 provided numbers of captures, injuries and mortalities (Table 1). An additional 11 organizations reported that they could not provide data because they do not systematically keep track of incidents at their stations, and 10 responded that they do keep track but could not assist us in our inquiries either because of reservations about sharing data or because data were not digitized or otherwise difficult to access.

The 22 contributing organizations reported 4782 incidents from a total of 620,997 captures. The average rates of mortality and injury were 0·23 ± 0·15 and 0·59 ± 0·68 respectively (per cent ± SD, Table 1). The overall rate of incident combining injuries with mortalities for all 22 organizations was 0·61 ± 0·66. Total captures for each organization varied from 717 to over 100,000 birds during study periods from two to 22 years. Seven organizations shared data sets from studies that have been operational for over 10 years and four of these for more than 20 years. The types of birds banded were predominantly passerines, but we also included organizations that specialize in the capture of raptors, shorebirds and hummingbirds.

Table 1. Mortality, injury and incident rates from 22 banding organizations in the United States and Canada. Table includes data from 620,997 captures and 4782 incidents

Organization	Types of birds banded	Mortality rate (%)	Injury rate (%)	Incident rate (%)
A	Passerines	0·56	0·14	0·7
B	Passerines	0·38	1·51	1·89
C	Passerines	0·36	0·48	0·84
D	Passerines	0·29	2·37	2·66
E	Passerines	0·28	1·04	1·32
F	Passerines	0·28	0·60	0·88
G	Passerines	0·24	0·14	0·39
H	Passerines	0·21	0·42	0·62
I	Passerines	0·18	0·38	0·56
J	Passerines	0·13	0·06	0·19
K	Passerines	0·07	0·15	0·22
L	Raptors	0·07	0·43	0·50
M	Raptors	0·00	0·00	0·00
N	Passerines			1·15
O	Shorebirds			0·38
P	Passerines			0·35
Q	Passerines			0·29
R	Hummingbirds			0·24
S	Passerines			0·10
T	Passerines			0·1
U	Passerines			0·1
V	Hummingbirds			0·03
Average ± SD		0·23 ± 0·15	0·59 ± 0·68	0·61 ± 0·66

Organizations N-V pooled injuries and mortalities together and are reported here as incidents. Organizations are reported without their names or number of captures to protect their anonymity.

TYPES OF INCIDENT

Of the five organizations that provided individual incident records, we identified 15 categories of injury (2247 records) and mortality (797 records, Fig. 1). With the exception of stress, cuts, accidents and incidents of unknown cause (which could occur either during banding or during mist netting) and band-related injuries (which occurred only during banding), all other injuries were directly related to the mist net and not to the handling and banding procedures.

Predation attempts were usually fatal, and the types of predators varied geographically. Common predators were reported by many of the 22 contributing organizations and included Sharp-shinned Hawks (*Accipiter striatus*), Cooper's Hawks (*Accipiter cooperii*), Northern Pygmy-owls (*Glaucidium gnoma*), Northern Shrikes (*Lanius excubitor*), Black-billed Magpies (*Pica hudsonia*), Eastern Cottontails (*Sylvilagus floridanus*), squirrels (*Sciurus* sp.), Eastern Chipmunks (*Tamius striatus*), White-tailed deer (*Odocoileus virginianus*), domestic cats (*Felis domesticus*), domestic dogs (*Canis familiaris*), foxes (*Vulpes* sp.), Weasels (*Mustela frenata*), Minks (*Neovision vison*) and Raccoons (*Procyon lotor*).

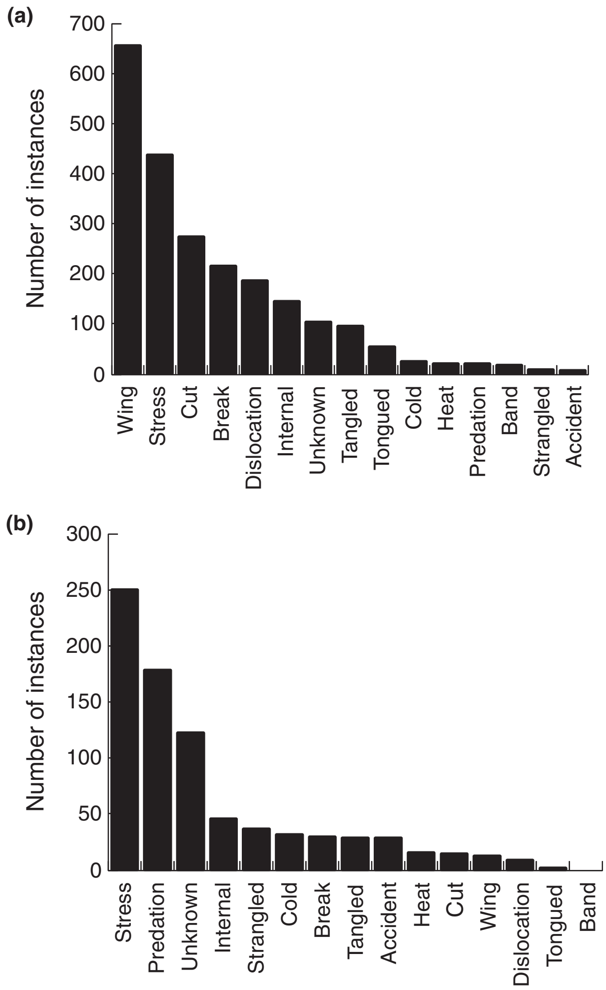

Fig. 1. Common categories of (a) injury and (b) mortality associated with mist netting and handling.

VULNERABLE SPECIES

Species was related to incident (LRT $P < 2{\cdot}2 \times 10^{-16}$, df difference = 35), and of the 36 most commonly captured species, four species had high rates of incident relative to the mean: Spotted Towhee, Allen's Hummingbird, American Robin and Western Tanager (Table S1, Supporting Information. All species names taken from the American Ornithological Union Checklist of North American Birds (2010)). These birds differed in the most common categories of injury. For example, Spotted Towhees and Allen's Humming birds were more prone to stress, whereas Western Tanagers and American Robins were more prone to wing strain (Table S1, Supporting Information).

INDIVIDUAL PREDICTORS OF RISK

The three top performing models for individual predictors of risk accounted for 97·6% of Akaike weight (Table 2, Supplementary Information Table S1) and contained random effects terms year, species, mist net station, species by year and year by station interactions. The probability of incident was most strongly associated with individual body mass (cumulative Akaike weight = 1, Table 3), capture number (cumulative Akaike weight = 1) and time of day (cumulative Akaike weight = 0·996). The predicted predicted number of incidents increased slightly from 5:00 am to noon from 3 to 3·5 birds per 1000 (Fig. 2). The predicted number of incidents more than doubled from three to seven birds per 1000 as individual body mass increased and declined from four to less than one incident per 1000 as the capture number increased. Sex, age, month of capture and mist net mesh size had little effect on the predicted number of incidents.

BODY SIZE

Species mass was negatively related to stress-related incidents, tangling and wing strain, while predation, internal bleeding, leg injuries, broken legs and cuts were positively related (Fig. 3). Likelihood ratios indicated significantly better fits for models including species mass for all eight categories of incident (predation $P = 3{\cdot}0 \times 10^{-9}$, stress P = P = $2{\cdot}20 \times 10^{-16}$, wing strain $P = 0{\cdot}027$, break $P = 0{\cdot}0041$, tangling $P = 9{\cdot}65 \times 10^{-5}$, internal bleeding $P = 0{\cdot}0065$, leg injuries $P = 0{\cdot}00030$, cut $P = 1{\cdot}92 \times 10^{-9}$).

POST-INJURY RECAPTURE

The overall recapture rate for injured birds was higher than for uninjured birds when all 16 species were pooled (percent recaptured ± SE (injured, uninjured) = 27·4 ± 2·9, 19·2 ± 2·6, $P = 0{\cdot}0032$ student's *t*-test). Additionally, we found no evidence for differences in recapture histories over any time-scales when comparing injured to uninjured birds with all species pooled (Fig. 4).

Discussion

For all organizations in this study, reported mortality rates were lower than the 1% target rate specified in Ralph *et al.* (1993). While the injury rate exceeded the mortality rate, combined rates fell below 1% for 18 of 22 organizations. These rates are lower than many studies published on the risk of capture and handling in other taxa. For example, the mortality rate of shorebirds captured with walk-in traps or mist nets, and subsequently blood sampled varied from 0 to 3% (Colwell *et al.* 1988) and was reported at 9% for raptors caught in bal-chatri, noose-harness and bow-net traps (Bedrosian & St. Pierre 2007). Several mammal studies that require leg traps (Blundell *et al.* 1999), snares or helicopter darting (Del Giudice *et al.* 2005) report mortality and injury rates above 1%.

Wing injuries, stress and cuts were the most common categories of incident. There was some ambiguity in how incidents were defined because of differences in classification by personnel among and within organizations. For example, many incidents of bleeding from the mouth assumed that an air sac had burst. However, necropsies of birds that hit windows have found that bleeding from the mouth is often a symptom of

Table 2. Fixed effects covariates included in three top performing models out of 53, including 97·6% of cumulative Akaike's information criteria (AIC) weight for individual predictors that affect the probability of injury or mortality in a mist net. Data are from 111,921 capture records in the PRBO dataset

Model	*k*	ΔAIC	*w*
Individual mass + age + sex + capture number + time	13	0	0·560
Individual mass + capture number + mesh + month + time	23	1·185	0·309
Individual mass + age + sex + capture number + mesh + month + time	27	3·312	0·107

All models include random effects terms year, species, mist net station, species by year and year by station interactions. Individual mass is the mass of each bird recorded for each capture record. *K* is the number of parameters. ΔAIC is the difference in AIC relative to the best model, and *w* is the Akaike weight.

Table 3. Relative support for fixed effect covariates from models of individual predictors of the risk of incident from the PRBO dataset. *N* is the number of models in which the covariate occurs w^+ is the cumulative Akaike importance weight for all models sharing a given covariate

Variable	*N*	w^+
Individual mass	29	1
Capture number	29	1
Time	28	0·996
Age	29	0·689
Sex	29	0·686
Mesh	28	0·436
Month	28	0·436

internal bleeding in organs and in the brain (Veltri & Klem 2005). Although it is unlikely that a correct diagnosis can be made for every incident, we are confident that patterns reported in this study identified the most common incidents. The adoption of systematic approaches to defining and reporting injuries across organizations could greatly reduce ambiguity in the categorization of incidents and could make it much easier to interpret patterns of common incidents across organizations.

Species-level differences in risk could be related to physiological and behavioural factors that probably predispose some species to injury. However, despite clear differences in incident risk between species within the same taxonomic group, we did not find obvious patterns in behaviour or anatomy that could explain why Spotted Towhees, Allen's Hummingbirds, American Robins and Western Tanagers were more prone to incident than other birds in the 36 species data set. Species-specific differences in antipredator behaviour may help to explain how birds respond to capture, which mimics the experience of being caught by a predator (Wilson & McMahon 2006). Behaviours such as predator mobbing, alarm calls and freezing are species-specific in birds (Nocera & Ratcliffe 2009) and could correlate with typical responses in captured birds. Likewise, among larger birds, wing and leg injuries may occur more frequently in some species than in others because of anatomical differences in wing size, leg length or ratio to body size that pertain to life history or foraging strategies, and those birds that use alarm calls may be more prone to predation in the net than those that freeze in the presence of predators.

Heavier birds were more prone to incident both within and among species. In the PRBO data set, individual body mass was positively correlated with the risk of incident within species, while in the analysis of body size and type of incident, species with greater average mass sustained different types of incidents than smaller species. Larger species were more prone to predation, which may be related to greater visibility in the net, or because they make more noise when they are caught. In a study of predation on birds in mist nets in Kenya, predation was most common on the Yellow-whiskered Greenbul (*Andropaduslatirostris*), which is larger and noisier than other birds in

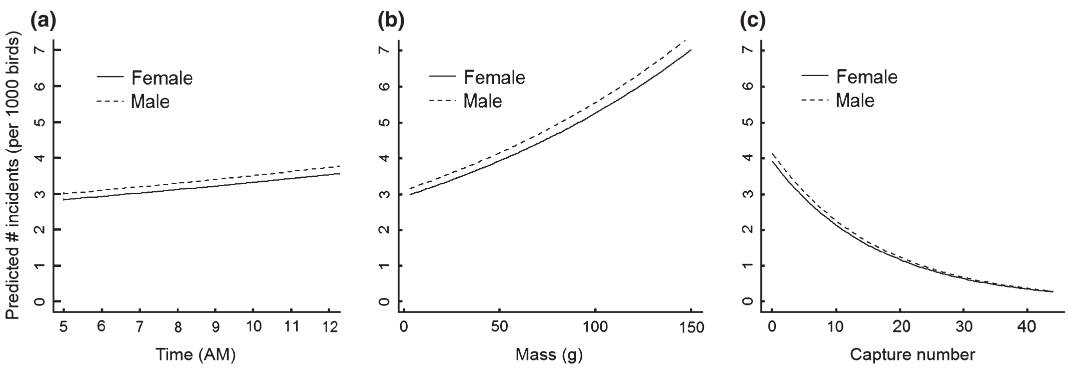

Fig. 2. Predicted numbers of incidents per 1000 birds from the PRBO dataset for male and female birds as a function of (a) time of day, (b) body mass (mass values are individual body measurements for each capture), and (c) the capture number (total captures for an individual). Results were model averaged across three top-performing models in the 95% confidence set (see summary Table 2, and additional details in Table S2, Supporting Information)

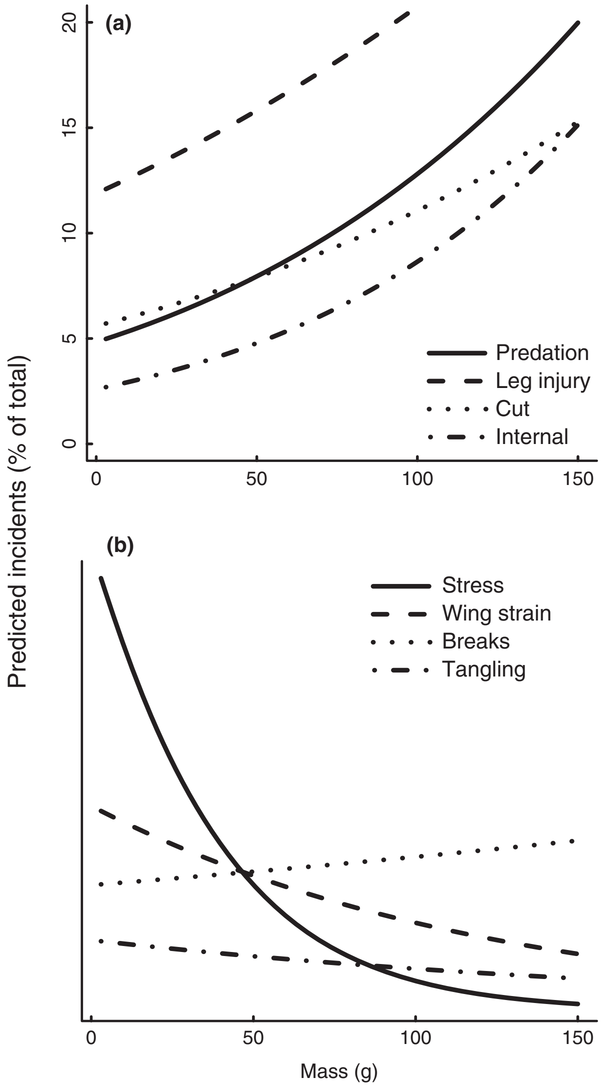

Fig. 3. Predicted percent of total incidents for eight types of incident for birds as a function of body size (mass values are species averages). Data are taken from five contributing organizations and include only incident records. Each model included species, organization, year, species × organization and year × organization random effects.

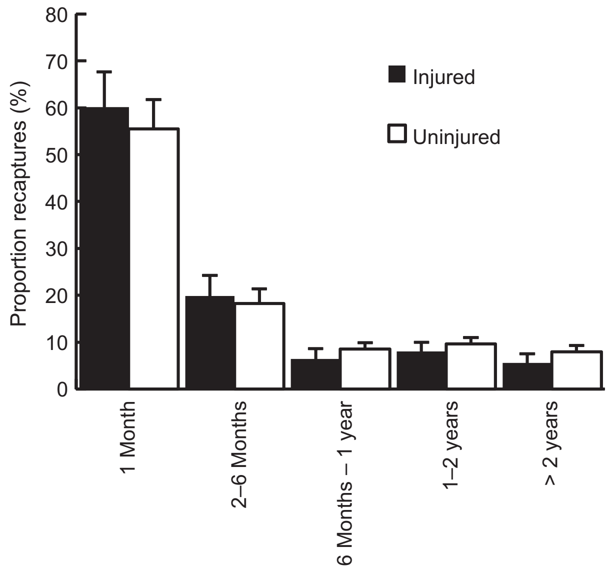

Fig. 4. Average recapture history over time for injured and uninjured birds from 12 species captured by PRBO between 1988 and 2008 and seven species captured by IBO between 1997 and 2008. Error bars represent 1 SE.

the study, and predation events tended to happen when nets had the highest numbers of birds in them (Brooks 2000). Larger birds may also be more prone to internal injuries, breaks, cuts and leg injuries because their size increases their impact with the net.

The stress response in birds is known to vary by species (Matson, Tieleman, & Klasing 2006; Cockrem 2007), but we found no evidence in the literature of a consistent trend with body mass that could explain why lighter birds were more prone to stress in our study. Smaller birds with faster metabolisms are known to thermoregulate differently than larger birds and thus respond differently to heat stress (Weathers 1981). In a recent review of stress responses in birds, small birds such as Great Tits (*Parus major*) had lower blood concentrations and a similar magnitude of elevation of corticosterone during capture (a hormone widely used to measure stress response in birds) than the much larger Adélie Penguin, *Pygoscelis adeliae* (Cockrem 2007). Whether or not the behaviours such as lethargy and eye closing that are used to identify stress by banders are truly correlated directly with stress cannot be determined without further research using blood samples to link corticosterone to indicator behaviours. Despite this limitation, these behaviours still indicate the possibility of a capture-related mortality and thus provide an important cue to banders when it is necessary to respond quickly to prevent mortality. Lighter birds were also found to be more prone to tangling and wing strain, which may be related to mesh size. In this study, only 30-, 32- and 36-mm mesh sizes were used, all of which target small passerines. While we did not find differences in the risk of incident across all species for these mesh sizes, lighter birds will tangle more in small mesh sizes than heavier birds which have wings that are larger than the mesh (North American Banding Council 2001). More tangled birds may have struggled more in the net resulting in longer extraction times, which could be responsible for increased risk of stress, tangling-injuries and wing strain in smaller birds.

In the PRBO data set, birds that were captured many times were less vulnerable to incidents. This pattern was persistent when mortalities were removed from the analysis, suggesting that the correlation was not caused by birds that had lower numbers of captures during the study period because they died sooner than those that remained uninjured. Mist net data include birds captured many times (likely to be resident near the mist net station) and transient individuals because most passerines that hit the nets are captured regardless of territorial or social status (Sillett & Holmes 2002). The PRBO data set includes large numbers of birds captured only once in the study period, many of which are likely to be transient individuals (Nur, Geupel, & Ballard 2004; Chase, Nur, & Geupel 2005).

Outside the migration season, transients are generally considered to be poor-quality younger birds that are less likely to possess territories (Newton 1998) and are likely to have lower capture numbers because they are less site faithful.

There was less support for age and sex as predictors of risk with young birds and females about as likely to sustain an incident as adults and males. While several studies have found lower survival estimates for birds between four and 14 weeks of fledging and breeding females compared to adults and males (Faaborg *et al*. 2010), in our study, these periods of reduced survival did not translate to increased risk of a mist net–related incident.

Additionally, the month of capture was not strongly associated with the risk of incident. While inclement weather is known to increase the probability of incident (North American Banding Council 2001), temperatures at the Marin County stations at PRBO on the central coast of California are relatively mild year-round, and weather conditions can be as variable within a season as between seasons (Chase, Nur, & Geupel 2005). Thus, any variation in risk of injury related to daily extremes in temperature were likely obscured by considering only the month of capture. Additionally, birds from the same species and those captured in the same year were not independent, indicating the presence of both yearly and species-level variation in the risk of incident. The time of day was an important variable in predicting the risk of incident, but there was only a slight increase in the number of predicted incidents throughout the morning, possibly because of increased wind later in the morning.

Injured birds had higher rates of recapture than uninjured birds. This could occur if birds that are injured remain in the area to recover after release more often than uninjured birds. However, among birds that were recaptured, the history of recapture over time was not different for injured and uninjured birds for any of the time periods evaluated, suggesting that birds that are released when injured continue to survive in similar numbers to those that are released uninjured. Because incident rates are consistently low, sample size limitations prevented us from conducting a statistically rigorous survival analysis of injured birds in spite of the large size of our data set. Such an analysis would provide a more robust assessment of the post-release fate of these individuals, and we encourage others to collect incident data so that these kinds of analyses can be conducted in the future.

There are other factors that may influence incident rates at mist netting stations that we could not test with our data set, including bander experience. Experienced handlers are generally able to extract and process birds more quickly, decreasing the handling time and possibly decreasing risk of incident. While it is important for continued research and monitoring for new banders to be trained in mist netting techniques, we recommend intensive supervision from a trainer until the trainee can safely extract and process birds captured in mist nets. All banders should follow the Bander's Code of Ethics (North American Banding Council, 2001) or other similar manuals from other countries and should constantly assess their own skill and encourage and offer feedback to fellow banders.

Conclusions

While the level of mortality and injury that should be considered 'normal' or 'acceptable' has not been defined for wildlife research, it does appear that compared to other techniques, mist netting has low rates of incident when conducted with bird safety precautions in mind and adequate training. Our results indicate that rates of mortality and injury below one per cent are achievable for projects utilizing mist nets to capture passerines and near-passerines. We were unable to control which organizations chose to share their data, and owing to the potential for bias in our sampling method, we cannot assume that our findings are representative of all organizations. However, the data presented here include numbers that have been achieved by some of the largest and longest-running organizations in the United States and Canada, most of which have highly developed protocols and rigorous training programmes to reduce the frequency of incident. We believe that these protocols probably contribute to the very low rates of incident in this study, and we recommend that similar protocols be adopted by all organizations using mist netting. We recommend banders follow guidelines provided in the Guidelines to the Use of Wild Birds in Research and in manuals published by the North American Banding Council, the British Trust for Ornithology or other similar manuals published in other countries (North American Banding Council 2001; Redfern & Clark 2001; Fair, Paul, & Jones 2010).

Incidents were rare events overall. However, our study highlights areas where banding organizations can focus attention. In particular, vulnerable species and individuals captured for the first time should be prioritized, and banders should identify which species are most vulnerable at their own sites. Personnel should pay attention to stress by using cues such as panting, lethargy, raising of feathers and closing eyes, and they should be particularly careful in recognizing stress cues for smaller birds. Banders should also watch for signs of wing strain and tangling in smaller birds and internal injuries, leg injuries, cuts and predation in larger birds.

While the tracking of incidents may appear tangential to research goals, these data are essential; without them, it is not possible to detect whether research data are biased by capture methods or to determine whether survival parameters derived from mark–recapture studies are biased by capture-related mortalities. Therefore, we encourage all banding organizations to consider adopting a consistent approach to the recording of injuries and mortalities, which should ideally include an assessment of which species are at highest risk and which injuries occur most frequently. These data will allow organizations to adjust their operations as necessary to minimize incidents.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Table S1. Rates and categories of injury and mortality in the 36 most common species in the regional dataset including 305,534 records from five banding organizations in order of logit estimates of the probability of incident.

Table S2. Candidate models for the analysis of individual predictors of risk using the PRBO dataset.

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