

Impacts of the live reef fish trade on populations of coral reef fish off northern Borneo

Helen Scales, Andrew Balmford and Andrea Manica*

Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK

The live reef fish trade (LRFT) is one of the greatest but least-quantified sources of fishing pressure for several species of large coral reef fish across the Indo-Pacific. For the first time we quantify the localized impact of the LRFT. We collected data from three LRFT traders in northern Borneo, which yielded information on daily fishing effort and the species and mass of all fishes sold every day by individual fishers or vessels over 2, 3 and 8 years. Total monthly catch and relative abundance (catch-per-unit-effort) declined significantly in several species, including the most valuable species the Napoleon wrasse (*Cheilinus undulatus*, estimated changes of –98 and –78% over 8 years in catch and relative abundance, respectively) and lower-value bluelined groupers (*Plectropomus oligocanthus*: –99 and –81%) and *Epinephelus* groupers (–89 and –32%). These severe declines were rapid, species-specific and occurred in the first 2–4 years of the dataset and are, we believe, directly attributable to the LRFT. This has crucial implications for future data collection and monitoring if population collapses in other parts of the LRFT and similar wildlife trades are to be successfully detected.

Keywords: live reef fish trade; coral reef fish exploitation; fish catch datasets; Napoleon wrasse

1. INTRODUCTION

The world's oceans have been routinely exploited for human consumption for at least 1000 years with widely documented impacts (Brander 1981; Tegner 1996; Jackson *et al.* 2001; Christensen *et al.* 2003; Dulvy *et al.* 2003; Sadovy & Cheung 2003; Rosenberg *et al.* 2005; Devine *et al.* 2006). In addition to harvesting marine species as a source of bulk protein, many fisheries supply demand-driven commodity markets (Hughes *et al.* 2003). These luxury wildlife trades are of particular conservation concern due to high prices which, coupled with strong demand, ensure incentives for persistent heavy exploitation. However, lack of long-term data limits monitoring and assessment of the impacts of these trades and hence the scope for effective management and conservation.

The live reef fish trade (LRFT) involves the exploitation of coral reef fishes from across the Indo-Pacific to supply luxury seafood restaurants (Johannes & Riepen 1995; Sadovy *et al.* 2003; Scales *et al.* 2006). The unsustainability of the LRFT is demonstrated by repeated boom-and-bust patterns of trade at a country level and a wave of exploitation spreading away from Hong Kong, the main centre of the trade (Scales *et al.* 2006). No studies have quantitatively assessed localized impacts of the trade on target species—mainly large-bodied groupers (Serranidae), wrasses (Labridae) and snappers (Lutjanidae) (Lee & Sadovy 1998). These species are inherently vulnerable to overexploitation due to a suite of shared life-history characteristics (e.g. slow growth rate, late age at maturity; Jennings *et al.* 1999; Morris *et al.* 2000; Reynolds *et al.* 2001; Sadovy *et al.* 2004; Sadovy 2005*b*). The rate of extraction of groupers for the LRFT is thought

to exceed potential sustainable yield (Sadovy *et al.* 2003; Warren-Rhodes *et al.* 2003), while ecosystem-level impacts of removing these species for the LRFT are largely unknown and likely to be complex (Jackson 2001).

We present the most detailed quantitative analysis to date of LRFT impacts using the data from live reef fish traders operating in northern Borneo where the trade has operated since 1980 and is anecdotally reported as being in decline (Bentley 1999). While there are various subsistence fisheries exploiting multiple species of coral reef fish in northern Borneo, inspections of local markets in Kudat revealed an absence of the particular species favoured by the LRFT (H. Scales & A. Manica 2001–2004, personal observations). Informal interviews with fishers also indicated that any captured specimens of desired species that can be kept alive are sold to the LRFT (H. Scales, unpublished data). Therefore, we believe that the declines observed in the daily catch data reflect the impact of the LRFT, since the species involved are rarely caught by other fisheries. Continuous daily fish catch data provided species-specific information on the mass of all the fishes sold to each trader over intervals of between two and eight years. We quantitatively assessed population-level impacts of the LRFT using changes in summed monthly total catch and catch-per-unit-effort (which indicates relative abundance of exploited populations). The longest dataset revealed dramatic species-specific declines in both total catch and relative abundance, which we believe to reflect the impact of the LRFT on populations of reef fish.

2. MATERIAL AND METHODS

(a) Study area and data collection

Daily fish catch data were collected from three LRFT traders in the Malaysian state of Sabah, northern Borneo in July 2002, 2003 and 2004—from two out of the nine traders in

* Author for correspondence (am315@cam.ac.uk).

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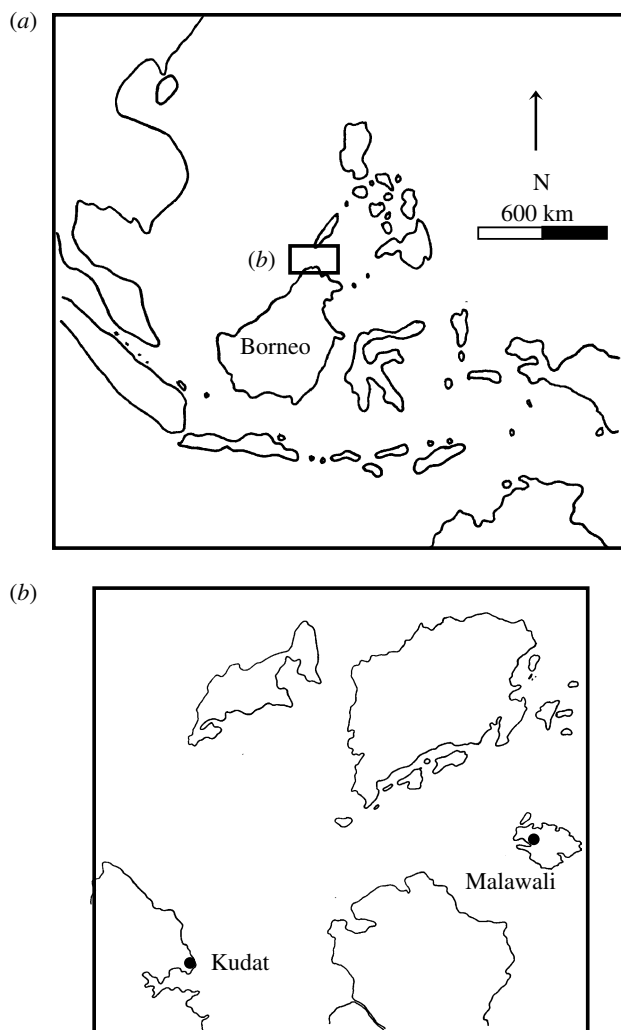


Figure 1. Maps of (a) Southeast Asia and (b) northern Borneo region showing location of three traders visited during the study.

Kudat (representing approximately 30% of the overall trade in Kudat; H. Scales & A. Manica, personal observations) and from the single trader on Malawali Island (figure 1). The structure of the LRFT commodity chain in Sabah is broadly representative of the trade across Southeast Asia (Bentley 1999). Traders recorded the daily total mass (kg) of each species (except for *Epinephelus* spp. groupers, which were lumped into a single category) brought in by individual fishers or boats.

The longest dataset was from one Kudat trader (Kudat 1), with data from January 1995 until January 2003 (excluding January 1998–July 1999, due to a missing record book; $n=2442$ daily records, because on several days no fishes were delivered). A second Kudat trader (Kudat 2) provided data from November 1999 to June 2003 ($n=763$ daily records; on several days no fishes were delivered). The Malawali trader provided data from August 2001 to August 2003 ($n=3815$ records; multiple records were made on most days).

(b) Data analysis

Relative abundance of each species in each dataset was estimated by dividing the daily total catch (kg) by either the number of fishers (in Malawali) or boats (in Kudat) operating each day, thus providing catch-per-unit-effort (kg per fisher or boat per trip). A single fishing trip by a Kudat boat was adopted as a constant unit of fishing effort since trip length

did not significantly change over time (gaps between consecutive visits to traders over 12 days were assumed to indicate a break in fishing and were excluded; linear mixed model of gap length predicted by date; likelihood ratio test for different slopes across boats = 0.202, $p=0.903$; change in gap length through time: $F_{1,774}=0.01$, $p=0.919$). Fishers in Malawali only fished one day at a time (H. Scales & A. Manica, personal observations).

We aggregated the daily data into monthly figures and used linear mixed models to analyse temporal changes in total catch and relative abundance for each species (both response variables were log transformed to linearize relationships), taking year as a fixed effect and month as a random effect, to account for seasonal trends. Year was set as a continuous variable, allowing the significance of linear trends through time to be tested. A fully saturated model (i.e. a model with all factors) was initially fitted and a minimal model (i.e. a model that included only factors that had a significant explanatory power) was subsequently obtained through backwards-stepwise elimination (Venables & Ripley 2002). Significance at $\alpha=0.05$ was adopted as the criterion for terms to be kept in the minimal model. This approach was preferred over more sophisticated time-series analysis (e.g. Box–Jenkins models) due to its robustness when faced with missing data and short time-series.

Our power to detect declines was determined by dataset length for which our three time-series differed markedly. To investigate the ability to detect trends in the shorter datasets, we repeated analyses on truncated versions of the longest dataset (Kudat 1).

3. RESULTS

Total monthly catches in the longest dataset (Kudat 1) declined significantly between 1995 and 2003 for all targeted species (changes range from -73 to -99% ; table 1 and figure 2). The monthly number of boats selling fishes to the Kudat 1 trader declined significantly between 1995 and 2003 ($R^2=0.58$, $n=76$, $p<0.001$). However, this reduction in total fishing effort did not always explain the declines in total monthly catches; relative abundance of three species (Napoleon wrasse -98% , *Epinephelus* -89% and bluelined groupers -99%) also declined significantly between 1995 and 2003 (table 1 and figure 2).

Results in shorter datasets were equivocal. Total monthly catches in the Kudat 2 dataset declined significantly between 1999 and 2003 for all species except spotted grouper (*Plectropomus maculatus*; table 1 and figure 2). The total monthly number of boats in the Kudat 2 dataset also declined between 1999 and 2003 ($R^2=0.30$, $n=35$, $p=0.001$). In contrast to Kudat 1, this reduction in fishing effort explained all the declines in total monthly catches in the Kudat 2 dataset, since none of the relative abundance trends declined significantly (table 1 and figure 2).

The shortest dataset (Malawali) revealed very few clear patterns. The only significant temporal change was an increase in the total monthly catch of Napoleon wrasse (table 1 and Fig. A1 in the electronic supplementary material).

Truncating the Kudat 1 dataset confirmed that lack of clear patterns in other time-series was probably due to their short coverage. Restricting the analysis to 1999–2003 data only from Kudat 1 produced a similar pattern to that

Table 1. Results of linear mixed models testing the temporal changes in total monthly catches (kg per month) and relative abundance (kg per fishing boat or per fisher per trip) \pm s.e. of target species in the LRFT from Kudat 1, Kudat 2 and Malawali datasets plus truncated Kudat 1 datasets. (Italic text shows estimated percentage change. —no data available for the species; *, tests significant at $\alpha < 0.05$ level; **, tests significant at $\alpha < 0.01$ level and ***, tests significant at $\alpha < 0.001$ level.)

species	total catch (kg per month, log transformed)			relative abundance (kg per fishing boat or fisher, log transformed)						
	1995–2003 Kudat 1	1999–2003 Kudat 2	1999–2003 Kudat 1	2001–2003 Malawali	2001–2003 Kudat 1	1995–2003 Kudat 1	1999–2003 Kudat 2	1999–2003 Kudat 1	2001–2003 Malawali	2001–2003 Kudat 1
Napoleon wrasse	-0.48 ± 0.03 -98%***	-0.60 ± 0.18 **	-0.54 ± 0.14 **	0.68 ± 0.23 *	0.19 ± 0.29	-0.19 ± 0.02 -78%***	-0.06 ± 0.11	-0.22 ± 0.15	0.03 ± 0.02	0.05 ± 0.14
leopard grouper	-0.17 ± 0.02 -74%***	-0.50 ± 0.12 ***	-0.06 ± 0.05	0.12 ± 0.13	-0.31 ± 0.14 *	0.02 ± 0.01 21%	-0.08 ± 0.07	-0.65 ± 2.23	0.003 ± 0.05	-0.35 ± 0.11 **
<i>Epinephelus</i> spotted grouper	-0.28 ± 0.03 -89%***	-0.56 ± 0.17 **	-0.29 ± 0.14	0.09 ± 0.16	0.32 ± 0.32	-0.05 ± 0.05 -32%***	-0.15 ± 0.08	0.08 ± 0.09	-0.003 ± 0.02	0.18 ± 0.11
spotted grouper	-0.20 ± 0.04 -80%***	-0.13 ± 0.23	-0.31 ± 0.15	0.003 ± 0.12	1.00 ± 0.26 **	-0.01 ± 0.02 -10%	-0.008 ± 0.08	0.57 ± 0.31	-0.03 ± 0.04	0.73 ± 0.12 ***
saddleback grouper	-0.17 ± 0.04 -74%***	—	-0.41 ± 0.14 **	—	-0.29 ± 0.28	-0.009 ± 0.008	—	-0.03 ± 0.04	—	-0.06 ± 0.05
squaretail grouper	-0.17 ± 0.04 -73%***	—	-0.30 ± 0.12 *	—	-0.29 ± 0.24 *	-0.001 ± 0.01 -4%	—	0.08 ± 0.11	—	-0.03 ± 0.11
bluelined grouper	-0.69 ± 0.07 -99%***	-0.47 ± 0.17 *	0.45 ± 0.16 **	—	1.10 ± 0.38 *	-0.21 ± 0.03 -81%***	-0.05 ± 0.06	0.25 ± 0.09 **	—	0.28 ± 0.13 *
all species	-0.20 ± 0.02 ***	-0.45 ± 0.11 ***	—	0.28 ± 0.14	—	-0.005 ± 0.01	-0.05 ± 0.05	—	0.04 ± 0.04	—

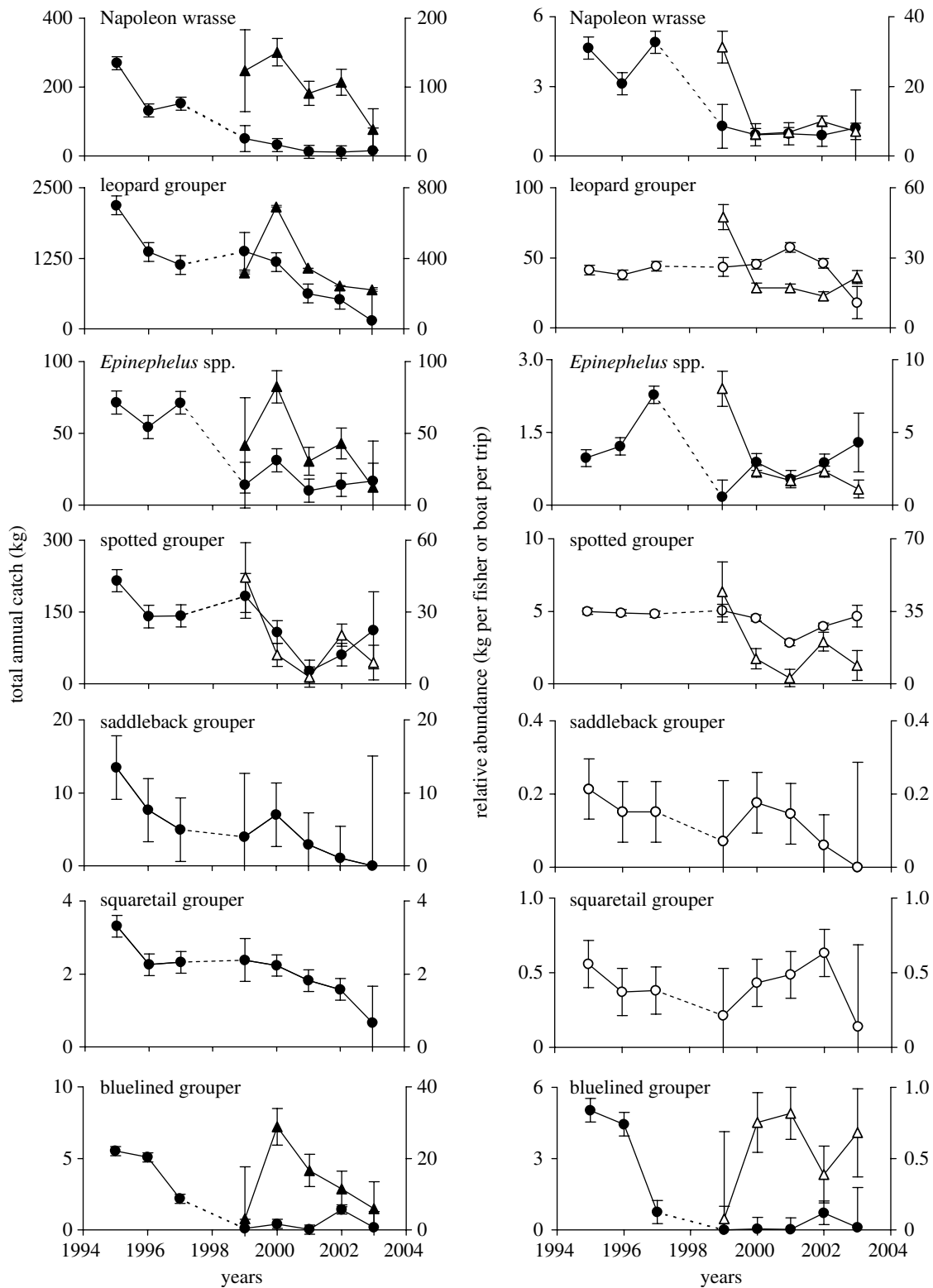


Figure 2. Mean (± 1 s.e.) total annual catches (kg) and relative abundance (kg per fisher or boat per trip) for Napoleon wrasse, leopard grouper, *Epinephelus* species, spotted grouper, saddleback grouper, squaretail grouper and blulined grouper from the Kudat 1 (circles) and Kudat 2 (triangles) datasets. Filled symbols indicate a significant temporal change at $\alpha=0.05$ level. Open symbols indicate non-significant tests. Broken lines span gap in Kudat 1 dataset.

in Kudat 2; while the total monthly catches of four species declined significantly, all but one of the relative abundance trends were non-significant (the trend for blulined grouper became positive; table 1). Likewise, taking 2001–2003 data from Kudat 1 produced inconsistent results; total catch and relative abundance declined in one species (and total catch in a second species), but

apparently increased in two others (table 1). All other trends were non-significant.

Finally, to test the importance of species-specific data for identifying temporal trends, we lumped species together and examined overall trends in catch and relative abundance. For Kudat 1 and Kudat 2, total catches declined significantly over time, but in neither case was

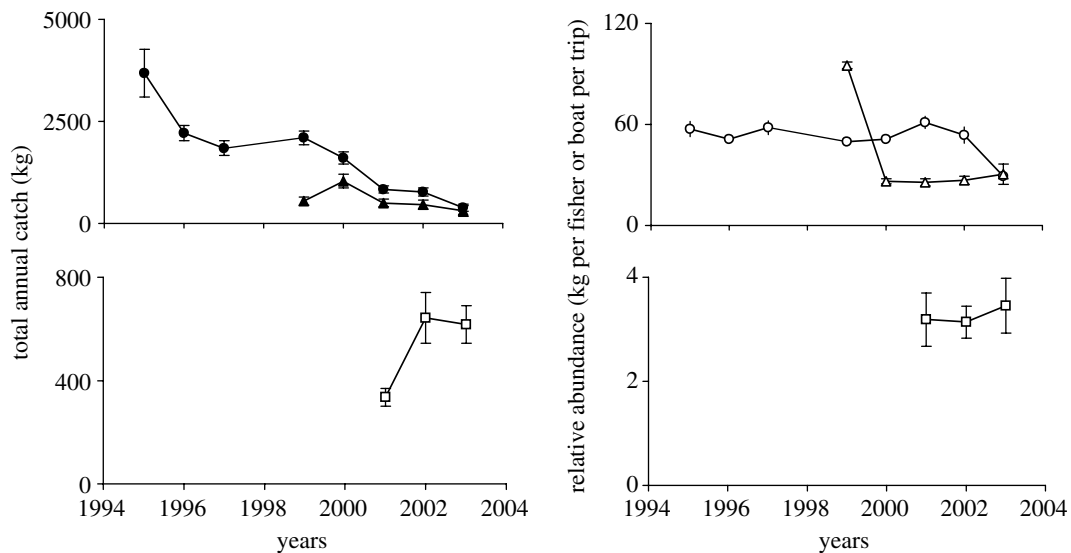


Figure 3. Mean (± 1 s.e.) total annual catches (kg) and relative abundance (kg per fisher or boat per trip) for all species lumped from three fish traders in northern Borneo: Kudat 1 (circles), Kudat 2 (triangles) and Malawali (squares). Filled symbols indicate a significant temporal change at $\alpha = 0.05$ level. Open symbols indicate non-significant tests. Malawali data (which are from a smaller fishery) are displayed separately for clarity.

there a significant trend in relative abundance over time (table 1 and figure 3). The Malawali datasets showed no significant trends over time (table 1, figure 3 and fig. A1 in the electronic supplementary material).

4. DISCUSSION

We found significant exponential declines of several coral reef fish species (in total catch and relative abundance) targeted by the LRFT in northern Borneo, which we interpret as the first quantitative evidence indicating severe population impacts of the trade. These declines took place in under a decade and are especially worrying given the mobile nature of the Kudat fishing fleet, since it is probable that vessels shifted range when nearby populations became depleted, thus maintaining catch rates for longer. The masking of serial depletions by spatial shifts in exploitation range is a major obstacle in assessing impacts of mobile fishing fleets on global marine resources (Berkes *et al.* 2006). That relative abundance in our datasets has nevertheless declined implies that population-level reductions were even more dramatic and sustained over a wide area. It is improbable that these trends were caused by other factors such as major changes in reef health; Borneo was relatively unaffected by the 1998 global coral bleaching event (Wilkinson 2000) and international trade statistics show that stocks of different LRFT species did not simultaneously collapse but were serially depleted according to market price (Scales *et al.* 2006).

It was necessary to assume that the daily effort per fisher or boat and allocation of effort between targeted species had not changed over time (this was supported by interviews with 112 fishers and 13 traders in the region; H. Scales, unpublished data). Any unaccounted changes in effort were most probably improvements rather than declines in gear efficiency and available technologies; thus if anything we have underestimated effort and hence overestimated relative abundance in later years.

We emphasize the crucial importance of obtaining datasets that are (i) long term, and (ii) species-specific, in

order to maximize chances of detecting temporal trends, including dramatic collapses in multi-species trades. A vital application of such datasets is to monitor naturally rare species, e.g. Napoleon wrasse, that are challenging to directly study in the wild. This is especially important for species listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which prohibits their trade without such population information (Sadovy 2005a). Our data, together with global boom-and-bust trends in the trade (Scales *et al.* 2006), are a stark warning that similar collapses may be expected throughout the LRFT and in other high-value wildlife trades, but without long-term datasets these trends may go undetected.

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