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ANALYSIS

The trade in babirusas and wild pigs in North Sulawesi, Indonesia

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Abstract

We collected two long-term datasets documenting the trade in two endemic wild pig species in North Sulawesi, Indonesia—a 6-year survey of the end market and records of all transactions by a wild pig dealer during three periods over a 10-year period. Analysis of these data show that the number of babirusas (an endangered, endemic, protected species of wild pig) on sale in the end market is strongly influenced by law enforcement activities, although dealer habituation is reducing the effects of these interventions. We demonstrate that dealers drove significantly farther to buy wild pigs, paid more for them and bought fewer in 1997 than 1988. These trends are consistent with resource depletion, but we show that they are also likely to be caused by market changes. We suggest that long-term, spatially explicit studies are important for the assessment of the sustainability of the wildlife trade, as they provide the potential for disentangling the influences of market dynamics from population declines, and thereby assist in interpreting changes in prices and quantities on sale in end markets.

Keywords: Babirusa; Sulawesi wild pig; Bushmeat; Hunters; Dealers

1. Introduction

Assessing the effect of hunting on endangered wildlife, particularly the local trade in wildlife from tropical forests, is of great conservation interest (Robinson and Bennett, 2000). Studies on the economics of the wildlife trade include those that report the quantity of wildlife sold in a market, as a snapshot or over time (e.g. Juste et al., 1995). Others look at demand on a household level, assessing the amount of meat that a household eats in a given period (e.g. Wilkie and Godoy, 2001; Wilkie and Carpenter, 1999; Njiforti, 1996), or analyse the behaviour of individual hunters (e.g. Marks, 1994; Alvard, 1995; Colell et al., 1994). Studies also exist on the effects of external factors such as roads or logging concessions (Ayres et al., 1991; Wilkie et al., 1992, 2000).

In this study, we analyse two long-term datasets on the trade in wild pigs in North Sulawesi (Table 1). These datasets are unique both in terms of

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Table 1
The data sources used in this study

	1988		1989		1990		1991		1992		1993		1994		1995		1996		1997		1998		1999	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
End market wild pig Q and P by species																								
Quoted											X	X	X	X	X	X								
Actual																			X	X	X	X	X	X
End market quoted Q and P (all meat & fish)																					X	X	X	X
End market actual P, household goods																				X	X			
End market actual pig meat Q and P over the day																						X	X	
Dealer records	X	X							X	X	X	X	X							X				
Dealer costs															X									

The period for which data are available is divided into 6 month intervals (1, January–June; 2, July–December). Q, quantity on sale; P, price. Quoted, price quoted to the market monitor; Actual, price paid by monitor.

detail and in the long time periods which they cover. The first comprises records of the number of wild pigs sold in the province's main end-market over a 6-year period, together with records of all the meat and fish on sale in the market over a shorter period. The second dataset comprises detailed records of the weekly transactions of a wild pig meat dealer at intervals over a 10-year period. Together, these data allow us to build up a comprehensive picture of the economics of the wild pig trade in North Sulawesi province: we address the effectiveness of conservation interventions in controlling the illegal component of the trade, the effects of major road improvements and the economic crisis of 1997–1998, changes in the behaviour of individual hunters and dealers, and the influence of the broad range of meats sold in the end market on the wild pig meat trade. Although we cannot undertake a full bio-economic analysis of the wild pig trade, we use the available data to draw conclusions about the sustainability of the trade, the appropriateness of various conservation policies, and the relative influence of resource depletion and market dynamics on hunter and dealer behaviour.

The datasets were collected as part of an ongoing conservation project being carried out by Lynn Clayton, which started in 1989. Project activities include awareness-raising of the legal and conservation status of endangered species among officials, dealers and the general public, protection of forest sites where endangered endemic species (including babirusas) can be observed, support for law enforcement activities by local officials, and market monitoring. The guarding of forest sites involves the use of army special forces in collaboration with government forest guards.

2. Background

The province of North Sulawesi is a long, narrow arm of land (25 000 km^2). At the time of the study, it comprised three districts (Fig. 1). Trade in wildlife is closely related to religious differences within the province; in Minahasa district 95% of the population are Christian while the two remaining districts, Bolong Mongondow and Gorontalo, are almost entirely inhabited by Muslim peoples. Wild meat is extremely popular with Minahasan people but is not hunted or consumed by most residents of Bolong Mongondow and Gorontalo.

Dealers in wild pig meat, all Minahasan, sell the meat in the markets of Minahasa, chiefly in Langowan, Tomohon and Kawangkoan (Fig. 1). They drive out in small pickup trucks to purchase meat from hunters at the forest edge or at collection points on a weekly basis. Today they mostly purchase in Gorontalo district, at the North/Central Sulawesi provincial border and in Central Sulawesi, a round trip of up to 2000 km. Dealers traditionally have their 'own' hunters, typically Minahasan, who regularly supply meat to them. The dealer transports them to a hunting area where they remain for 2–6 months at a time before moving to a different forest area.

The major targets of the hunters are wild pigs, which they catch using nylon leg snares. There are two species of wild pig, both endemic to the island of Sulawesi. The babirusa (*Babyrousa babyrussa*) is an extraordinary curly-tusked pig, which is limited in distribution to rain forest areas (Clayton, 1996). It is found at low densities, has a low intrinsic rate of population increase and is estimated to number only around 5000 individuals. It is a protected species, meaning that it is illegal to hunt, kill or trade the species. The Sulawesi wild pig (*Sus celebensis*) is relatively abundant and much more resilient to human disturbance and hunting, although it too has been locally exterminated by hunting in some parts of the province. Snaring is a relatively indiscriminate method of hunting, catching both species of pig. Modelling has shown that hunting for the commercial trade is likely to lead to rapid local extirpation of babirusas while the presence of Sulawesi wild pigs continues to make hunting in an area economically worthwhile (Clayton et al., 1997; Keeling et al., 1999).

The number of dealers and hunters working in the wild pig meat trade has increased dramatically in recent years. In 1948–1970 there was only one wild pig meat dealer operating in North Sulawesi; two more dealers became active in 1970–1984, 12 full-time dealers were active in 1993. In 1996,

there were about 30 dealers active in the province. The dealers have benefited enormously from recent road improvements, allowing them to travel faster and further to buy meat. Just one major road links Minahasa with the Gorontalo region (Fig. 1). This road first became passable in 1980, although then it was necessary to raft vehicles across major rivers; it was first fully tarmacked in 1992.

The wild pig trade in North Sulawesi is unusual. In most parts of the world, wildlife hunters are predominately locals who hunt primarily for subsistence use. In North Sulawesi, wild pig hunting is purely commercial, and is carried out largely by Minahasan people, rather than by local people in the areas where the animals occur. The wild pig trade is discussed in more detail in Clayton and Milner-Gulland (2000), while Lee (1999) describes the wildlife trade in North Sulawesi more generally.

3. Methods

Langowan is the most important market for wildlife in Minahasa province, particularly for babirusas, and hence was the main focus of the study. In 1993–1995, Langowan accounted for

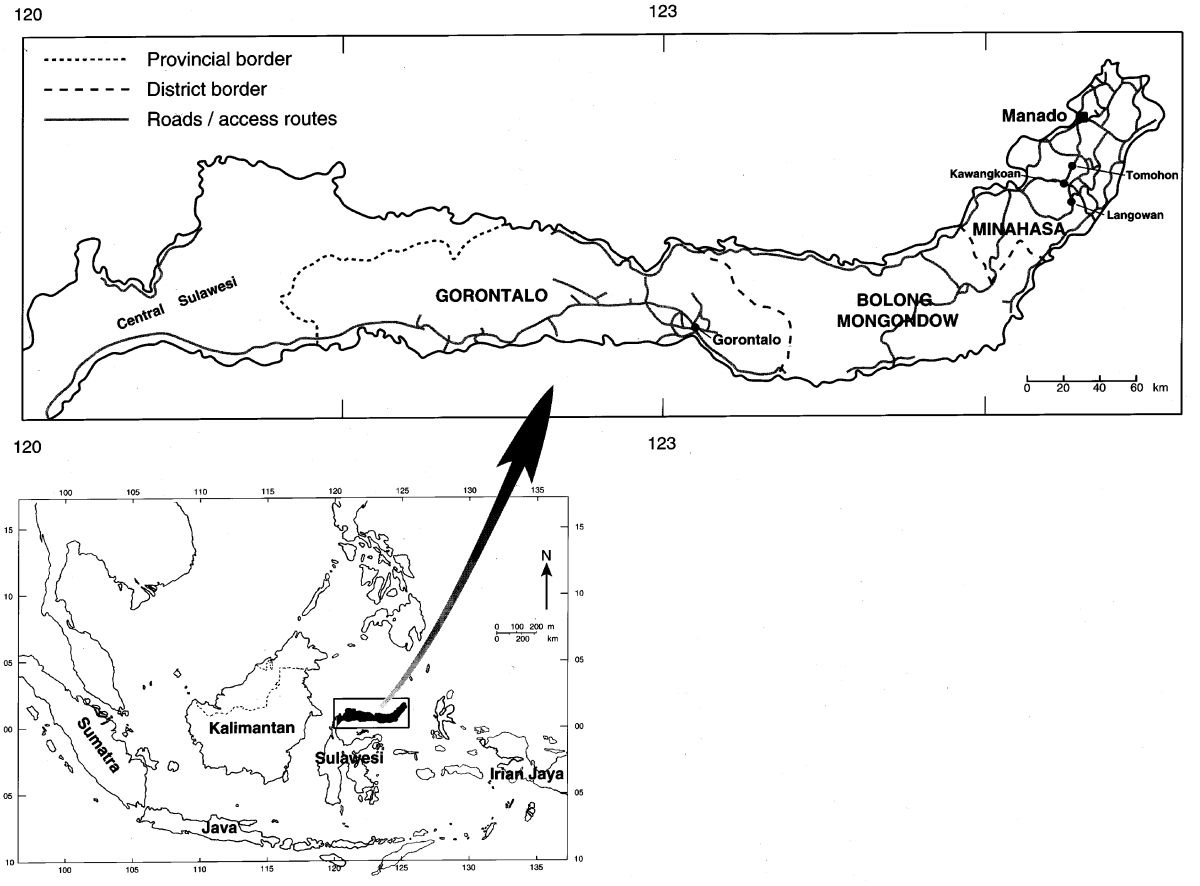

Fig. 1. A map of North Sulawesi province, showing the places mentioned in the text. At the time of the study the province was divided into three districts, as shown here. Gorontalo district has recently been divided in two, with the western part renamed Bolaemo. North Sulawesi is now being split into two provinces; one will include Minahasa and part of Bolong Mongondow, the other the rest of Bolong Mongondow, Gorontalo, Bolaemo, and possibly part of Central Sulawesi.

67% of the wild pigs sold each week, and 99% of the babirusas sold. The market was monitored over a 6-year period by a local woman who habitually shops there. The fact that she aroused no suspicion when enquiring about meat prices means that the data on the quantity and price of meats on sale in the market are likely to be reliable. She was also able easily to identify all the species on sale in the market. The monitor visited Langowan market three times a month and counted the total number of meat products on sale in the market, as well as asking their price. Some surveys were also carried out in which she revisited the market to monitor changes in prices and quantities over the course of a day. In order to check for systematic differences between quoted and actual prices, she occasionally bought goods rather than simply asking for a price. On one Saturday each month she surveyed Tomohon and Kawangkoan markets, where wildlife is also known to be sold. Saturday was chosen because it is the busiest market day, and the one with the most wildlife on sale; occasional visits to the markets on other days confirmed this to be the case. Seven o'clock in the morning was chosen as the peak time of the market, when the maximum amount of meat is on sale.

Data on the activities of wild pig dealers were obtained from the detailed accounts of the business transactions of a case study dealer (dealer X). This was particularly valuable because the dealer has been in the trade for a very long time; he was the first full-time wild pig trader in North Sulawesi, and has traded continuously in wild pigs since 1948. Until 1979, he purchased wild pigs and dogs 100 km west of Manado (Fig. 1). With the opening of the trans-Sulawesi highway in 1980, he began purchasing at the Minahasa/Bolong Mongondow border and extended his journey westwards to the middle of Gorontalo district by around 1990. Thus, it is possible to trace the development of the wild pig trade through the experiences of this particular dealer. His movements west are especially important in tracing the depletion of wild pig populations along the trans-Sulawesi highway; as the wild pigs in an area have been hunted out, the dealer has had to drive further in order to buy meat. At the same time, the road improvements have allowed him to drive further, and still get back to the market before the quality of the meat deteriorates enough to make it unsaleable.

The use of one person's accounts as a case study necessitates the assumption that he is relatively representative of the trade as a whole. This was checked qualitatively by observation and discussion with other dealers, which suggested that dealer X was not unusual in his trading activities. Dealer X's detailed accounts were available for three periods: 11th April–28th December 1988, 6th December 1991–30th June 1994, and 12th June–27th December 1997. In each of these periods, data were available for every trip that the dealer made to buy wild pigs (trips usually took place every week). The data include the location at which each pig was bought, its age class or weight in kgs, the name of the hunter selling the pig and the price paid. These data cover 171 trips, on which a total of 5421 pigs were bought by the dealer. The main limitation of these data is that the dealer's records do not distinguish between babirusa and Sulawesi wild pig meat because trading in babirusa meat is illegal while trade in Sulawesi wild pig meat is not.

In order to convert actual monetary values into real values, inflation figures were used from the Indonesian Government Statistical Office in Manado, the provincial capital. It was necessary to use local inflation figures because of the large regional variability in economic performance within Indonesia.

4. Results

4.1. The market

Table 2a–d gives an overview of the real prices and quantities of all fish and meat products on sale in Langowan market over the 2-year period 1998–1999. This gives an impression of the broad range of products available to consumers, all of which are potentially substitute goods for each other. The table shows that quantities of wildlife and wild-caught fish on sale in the markets are much more variable than those of farmed meat

Table 2
The prices and quantities of goods on sale at 07:00 h on a Saturday in Langowan market, 1998–1999
(*a*) *Average number of individuals of wildlife species on sale*

	Babirusa[c]	SWP[c]	Rats[e]	Cuscus[f]	*Kecil*[g]	*Lolak*[h]	Monkey[i]	*Bat punti*[j]	Fruit Bats	Fresh fish[k]	Smoked fish[k]
1998	8 (0.53)[l]	71 (0.15)	213 (0.34)	6 (0.64)	4(1.13)	34 (1.60)	1 (1.66)	25 (1.20)	84 (0.89)	3821 (0.76)	16 564 (1.07)
1999	11 (0.42)	64 (0.16)	229 (0.44)	4 (0.83)	6 (1.11)	134 (0.79)	1 (0.87)	34 (1.68)	70 (0.87)	5117 (0.58)	12 322 (0.55)
Year[a]	NS[d]	*	NS	**	NS	***	*	NS	NS	NS	NS
Christmas[b]	NS	***	*	NS	*	***	–	***	***	NS	NS
Festival[b]	NS	NS	***	NS	**	NS	–	NS	NS	NS	NS

(*b*) *Average price of wildlife species on sale*

	Babirusa	SWP	Rats	Cuscus	*Kecil*	*Lolak*	Monkey	*Bat punti*	Fruit Bats	Fresh fish	Smoked fish
1998	2952 (0.18)[m]	3150 (0.15)	1380 (0.28)	2491 (0.22)	915 (0.30)	962 (0.21)	12 125 (0.53)	1545 (0.25)	2081 (0.19)	248 (0.96)	1143 (1.12)
1999	3292 (0.15)	3362 (0.16)	1396 (0.09)	2528 (0.18)	906 (0.29)	874 (0.19)	40454 (0.50)	1439 (0.13)	2261 (0.20)	448 (0.50)	788 (0.55)
Year	*	NS	NS	NS	NS	NS	***	NS	NS	***	NS
Christmas	***	*	NS	NS	NS	NS	NS	NS	NS	NS	**
Festival	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS

(*c*) *Average number of individuals of domestic species on sale*

	Pigs	Dogs[n]	Cows	Farmed fish (carp)	Farmed fish (*Mujair*)[o]	Farm Chicken[p]	Village Chicken[p]
1998	25 (0.25)	33 (0.39)	1 (0.36)	574 (0.80)	1976 (0.36)	8 (0.74)	126 (0.45)
1999	27 (0.40)	30 (0.35)	2 (0.32)	214 (1.29)	1652 (0.37)	15 (0.58)	87 (0.48)
Year	NS	NS	***	***	NS	***	**
Christmas	***	*	–	***	***	***	NS
Festival	***	NS	–	NS	**	***	*

Table 2 (Continued)

(*d*) *Average price of domestic meat products on sale*

	Pork (*Hass*)[q]	Pork (Meat/Bone)[q]	Dog	Beef	Farmed fish (carp)	Farmed fish (*Mujair*)	Farm chicken	Village chicken[r]
1998	3695 (0.08)	3017 (0.10)	2555 (0.11)	3920 (0.11)	2862 (0.17)	2741 (0.17)	2926 (0.08)	3976 (0.07)
1999	3938 (0.03)	3123 (0.07)	3026 (0.05)	5130 (0.12)	3452 (0.11)	2924 (0.08)	3547 (0.13)	4839 (0.09)
Year	***	NS	***	***	***	NS	***	***
Christmas	NS	NS	NS	**	NS	NS	NS	**
Festival	NS	NS	NS	NS	NS	NS	NS	NS

[a] Year shows the results of a *t*-test for differences between the 2 years.

[b] The price and/or quantity of some species increase dramatically at festival times. This is shown by carrying out a *z*-test for the likelihood that the datapoints for Christmas 1998 and the harvest festival in 1999 come from the dataset of all observations apart from these two dates. The test is only carried out when the mean number of animals sold per day is >4.

[c] Babirusa is an endangered endemic wild pig, Sulawesi wild pig (SWP) is an endemic wild pig. Both are traded by dealers along with domestic dogs.

[d] Significance: ***, $P<0.001$; **, $P<0.01$; *, $P<0.05$; NS = $P>0.05$.

[e] Rats are of various Muridae species trapped locally.

[f] Cuscus is a poorly-known endemic dwarf cuscus (*Strigocuscus celebensis*).

[g] *Kecil* is a species of squirrel.

[h] *Lolak* is a species of rat.

[i] Monkey is one of three endemic, legally protected macaque species (*Macaca hecki*, *M. nigrescens*, *M. nigra*).

[j] *Bat punti* is a species of insectivorous bat.

[k] Fresh fish is an average of six species of fresh wild-caught fish, smoked fish is an average of four species of wild-caught fish.

[l] The table shows the average number of individuals on sale, with the coefficient of variation in brackets.

[m] Prices are in real Rupiah deflated to January 1988 prices, when 2200 Rupiah equalled one US$ (CV in brackets). All prices are per individual apart from babirusa and Sulawesi wild pig, which are per kg.

[n] Although dogs are domestic, they are traded along with the wild pigs by dealers.

[o] *Mujair* is a species of farmed fish.

[p] Farm chicken is intensively reared for sale, village chicken is a free-ranging chicken.

[q] *Hass* is high quality bone-free pork, Meat/Bone is pork containing both meat and bones.

[r] All prices are given per kg except for village chickens, which are per individual.

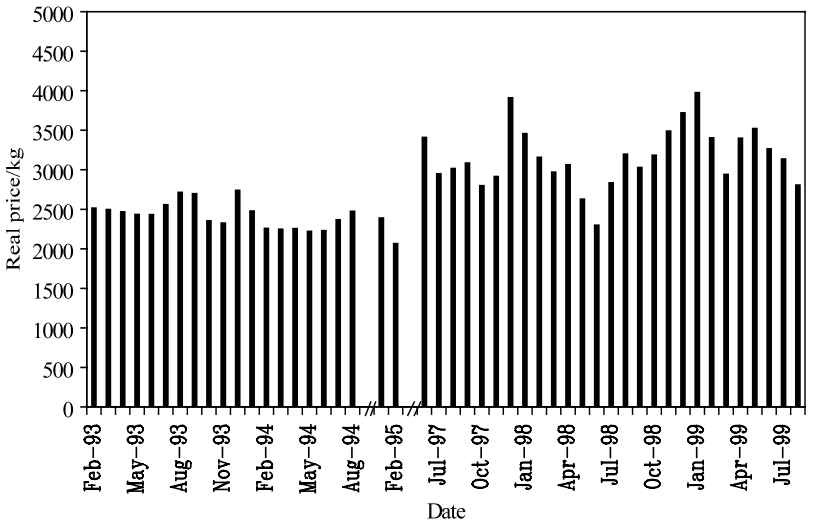

Fig. 2. The real price per kilogram (in Rupiahs deflated to January 1988) of wild pigs in Langowan market (babirusas and Sulawesi wild pigs combined), February 1993–August 1999. The data for 1993–1995 are quoted prices per kg, the data from 1997 onwards are the actual price per kg of a small piece purchased by the market monitor. There is a significant increase in price between these two time periods, but no trend in price within the periods.

like pork and beef, and prices slightly more variable. There is a clear influence of Christmas on prices or quantities supplied (and a lesser one of the harvest festival) for many meats, particularly those whose supply can be planned (such as pork). In many cases the quantity supplied is higher at Christmas, sometimes the price is too. The overall time trend in prices and quantities supplied varies between products, but real prices (inflation-adjusted) tended to be higher in 1999 than 1998. We did not observe short-term changes in real prices of meat, wild or domestic, during the 1997–1998 economic crisis in Indonesia, although the real prices of goods such as coffee, margarine, onions and rice did show large short-term increases.

Market data exist for wild pigs over a longer period than for other meats; data are available from 1993 to 1995 and 1997 to 1999. There is no consistent price difference between the two species of wild pig (paired t-test of data from 1998–1999, $t = -0.48$, $df = 35$, NS). The real price of both increased significantly between the two monitoring periods (Fig. 2). The data collected in 1993–1995 were based on quoted prices, whereas in 1997–1999 the data are based on the actual price of a quantity of meat bought by the market monitor. This change in sampling method is unlikely to be the cause of the price increase, as no systematic bias was observed on the occasions on which the monitor obtained both a quoted and an actual price. However, actual prices tend to be more variable than quoted prices (Fig. 2).

It would be expected that both the quantity and price of pig meat should vary over the day, given that it is a perishable good. However, although our data show that the amount of wild pig meat and pork on sale declines dramatically over the course of a day, there is no significant accompanying drop in price (Fig. 3). This result suggests strong substitution between meats in the market, which is consistent with a highly competitive market; this would lead to there being no clear link between price and the quantity of a particular meat on sale on a given day. This is also consistent with the lack of clear links between prices and quantities observed on festival days (Table 2). One might expect prices to drop over the day if the meat was highly perishable, as suggested in interviews with dealers and consumers. The fact that there is always very little meat left over at the end of the day also suggests the dealers are at-

tempting to minimise wastage. Thus the result that prices do not drop over the day is counter to expectations and may require further investigation.

There is no significant change over time in the total amount of wild pig meat on sale, although there was significantly less babirusa meat on sale in 1997–1999 than in 1993–1995, both actually and as a proportion of the total number of wild pigs on sale (Fig. 4). The amount of babirusa

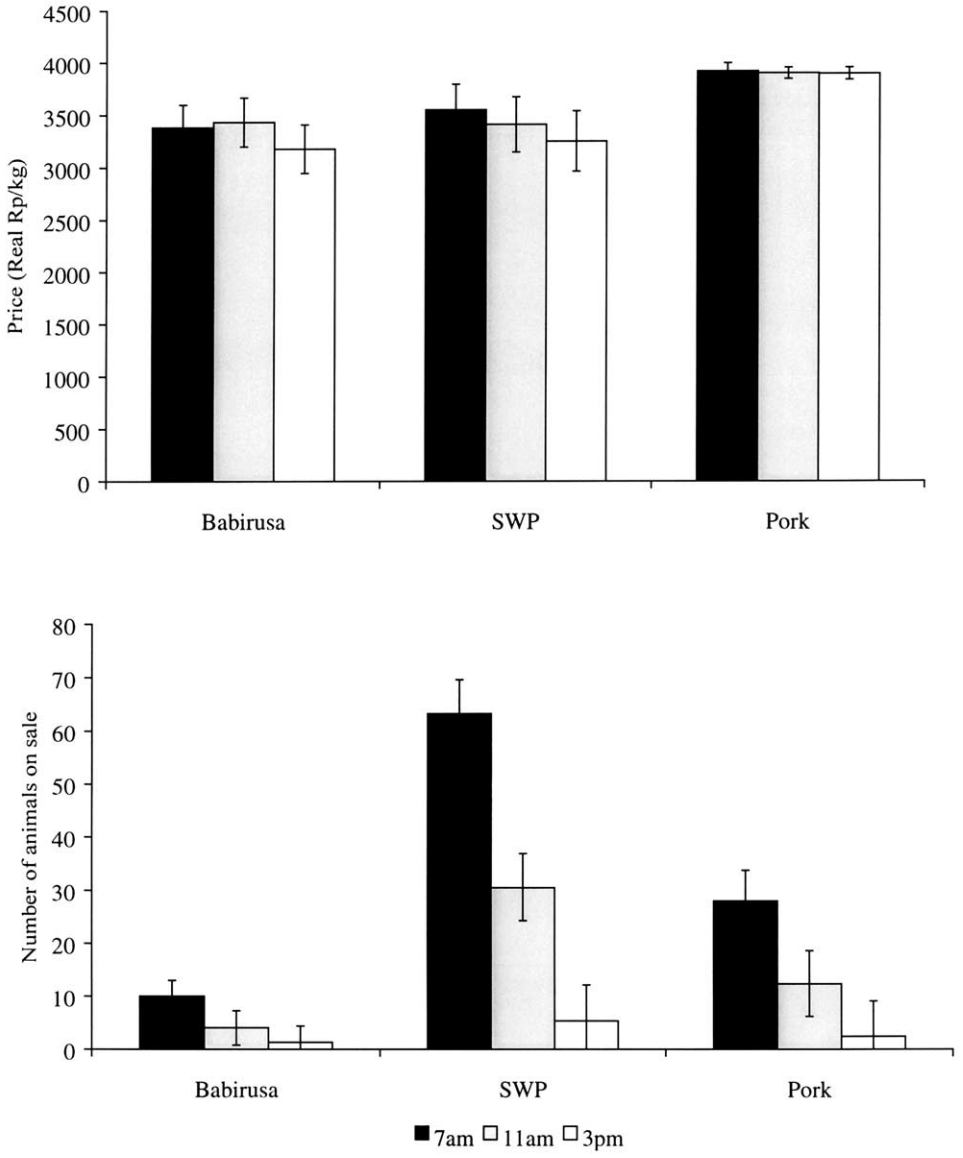

Fig. 3. The effect of the time of day on (a) the real price (in Rupiah, deflated to January 1988), and (b) the quantity of Sulawesi wild pig (SWP), Babirusa and domestic pork on sale in Langowan market. Data are the mean of 13 sets of observations (with 95% confidence intervals), carried out approximately every 4 weeks over the year September 1998–September 1999. The monitor obtained prices and quantities on sale at 07:00 h (start of the market day), 11:00 h and 15:00 h (end of the market day). The type of pork used is *hass* (see Table 1d). Actual prices were obtained for Babirusas and SWP, quoted prices for *hass*.

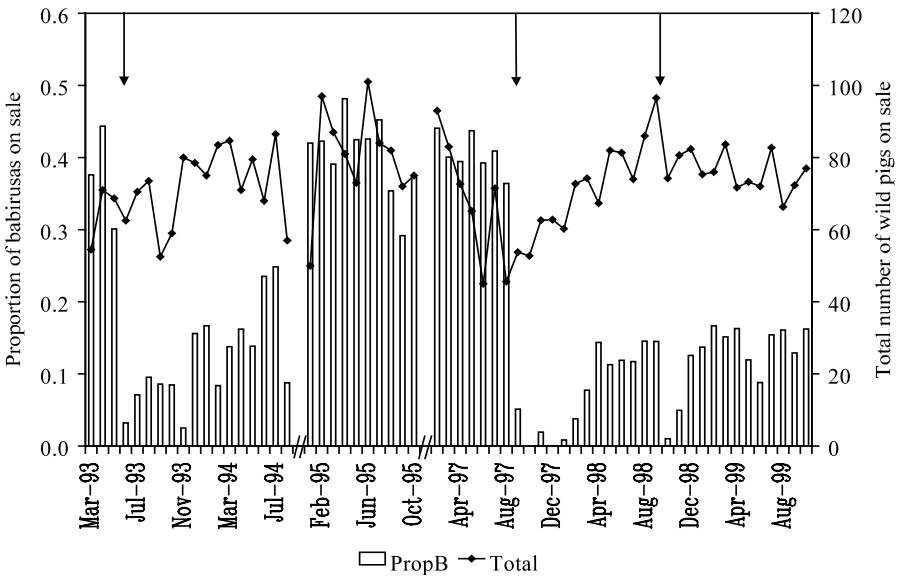

Fig. 4. The number of wild pigs on sale at Langowan, 1993–1999, and the proportion of the sales that are babirusas (a protected species, the sale of which is illegal). The total number of wild pigs on sale does not vary significantly with time, but the proportion of babirusas (PropB) varies greatly according to law enforcement and conservation actions. The arrows show dates on which law enforcement actions took place (including overnight checkpoints on the road used by dealers and visits to the end markets by government wildlife staff looking for endangered species on sale). Note the lack of observations in the periods September–December 1994 and November 1995–January 1997.

meat on sale is clearly influenced in the short- to medium-term by law enforcement activity. There have been three episodes of law enforcement activity during the study period, involving overnight checkpoints on the Trans-Sulawesi highway and visits to the market by government wildlife staff. Traders were detained at these checkpoints and had any protected species confiscated. No prosecutions have followed, although in 1993 a dealer paid a substantial sum to avoid a court case. The law enforcement episodes all caused a reduction in babirusa sales. The first one in 1993 caused a dramatic drop in the number of babirusas sold, which lasted for more than a year; the two subsequent visits were followed by increasingly rapid recovery to underlying levels of sales (Fig. 4). This pattern is consistent with the habituation of traders to law enforcement activity leading to less and less dramatic reactions as their perceptions of the risk of punishment linked to these visits are refined.

Apart from law enforcement episodes, there has been an increase in the level of awareness about the illegality of babirusa trade over the study period caused by our project activities. These include public education, guarding of particular forest sites and discussions with dealers and villagers. Our activities were stepped up from 1997 onwards. The effect of this change in policy environment is difficult to disentangle from the possible effects of depletion of the babirusa population. However, indirect evidence for its success may be drawn from the fact that from early 1993 up to mid 1997, the baseline proportion of the wild pig meat trade made up of babirusas was around 39% (Fig. 4). Since June 1998, it has stabilised at around 14% of total wild pig sales (ignoring the effects of episodes of law enforcement). The fact that this reduction in the proportion and number of babirusas on sale is a shift rather than a trend suggests that it may be caused by a change in perceptions and behaviour among consumers or dealers, rather than a change in the availability of babirusas.

4.2. The case study dealer

The data from the case study dealer are for both Sulawesi wild pigs and babirusas lumped together; it is not possible to distinguish between the two because trading in babirusas is illegal, and the dealer could not give us details of any illegal activity. This problem is a major drawback in using the case study dealer's data to infer depletion of the endangered babirusa. Our previous work (Clayton et al., 1997) suggests that the differing biology of the two species causes rapid depletion of babirusas in hunted areas while Sulawesi wild pigs remain relatively abundant. This makes overall market data unrepresentative of the true pattern of depletion because the end-market contains meat from many locations at different stages of depletion. However, it is still possible to use the dealer's data to understand and predict dealer behaviour, and to uncover evidence concerning the depletion of the joint stock of wild pigs.

Data were available on all the transactions made by dealer X in three time-periods (Table 1). Between these periods, there was a significant reduction in the quantity of wild pigs bought by the dealer, accompanied by an increase in the price paid per pig (Table 3). There has also been a significant increase in the time that the dealer drives in order to purchase pigs, with the mean time driven increasing from 563 mins (for a one-way journey) in April 1988 to 734 mins in December 1997 (ANOVA test: $F = 793.3$, $df = 44$, $P < 0.001$, Fig. 5). The time taken is calculated as the time to each pick-up point weighted by the number of pigs bought there. The maximum time driven on a trip increases along with the mean, but the minimum time driven increases at a slower rate, which is likely to be because of continuing opportunistic pick-ups along the way. Thus the distribution of mean time taken is getting more skewed over time, with a longer tail at the low distance end. These results bear out anecdotal observations that wild pigs have disappeared from locations nearest to the markets, and that dealers are now travelling farther to buy pigs, suggesting a wave of depletion emanating from the market towns.

Since dealer X recorded the names of the hunters supplying him, it is possible to examine changes over time from the perspective of individual hunters. By looking at the number of pigs supplied by particular individuals, we can see that the reduction in the mean number of pigs that the dealer buys is caused more by a reduction in the number of very large catches than by a change in the modal number of pigs supplied by a hunter each trip (Fig. 6), and that the increase in the mean price paid per pig is accompanied by an increase in the variability surrounding the mean price (Fig. 7). Changes in the number of pigs caught per hunting trip may be caused by a number of factors, both biological and economic. These include depletion of pig populations;

Table 3
Changes in the case study dealer's transactions between three periods; 1988, 1991–1994 and 1997

Statistics per trip[a]	1988[b]	1991–1994[b]	1997[b]
Number of pigs bought	56 (0.30)[c]	27 (0.41)	17 (0.40)
Number of hunters bought from	15 (0.20)	11 (0.28)	9 (0.37)
Number of pigs bought/hunter	3.8 (0.25)	2.4 (0.28)	1.8 (0.22)
Total expenditure on wild pigs ('000 Rp)[d]	392 (0.29)	192 (0.44)	227 (0.45)
Mean price per pig ('000 Rp)	7.1 (0.05)	7.2 (0.16)	13.7 (0.16)
Mean pay per hunter ('000 Rp)	27 (0.24)	17 (0.31)	24 (0.21)

[a] All the data are values per trip (the dealer makes approximately one trip per week to purchase wild pigs at the forest edge, and then returns to sell these pigs in the market).

[b] Sample sizes: 1988, 36 trips; 1991–1994, 111 trips; 1997, 24 trips.

[c] The figures given are means over all trips within each period (CV in brackets). All are significantly different between the periods (ANOVA test, $P < 0.001$).

[d] All prices are real prices, deflated to January 1988.

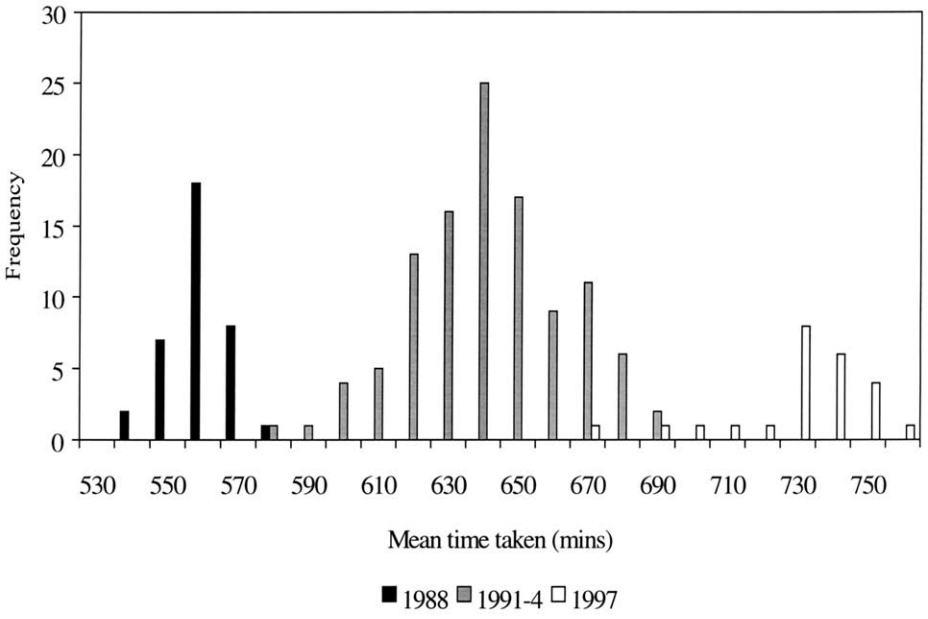

Fig. 5. Frequency distributions of the mean time taken for the dealer to drive on a one-way journey to buy pigs in 1988, 1991–1994 and 1997. The mean time per trip is calculated as the time to each of the pick-up points weighted by the number of pigs bought at each pick-up point. Times are given in minutes.

changes in hunter behaviour; changes in pig behaviour; a shift in the species composition of the offtake; or an existing spatial trend in pig population densities. Further research into wild pig biology and catch and effort data by species at the level of the individual hunter are needed to distinguish between these factors.

Both overall and within a particular time-period, it would be expected that the longer it takes to get to a destination, the less depleted it should be, and so the higher the total offtake of pigs should be. In this case, we can effectively assume that there is only one end-market, and so we test for depletion by regressing the number of pigs bought in a given location (both the total and the number bought per hunter) against the date of the purchase and the time taken to get to that location. The results are similar whether the total number of pigs bought or the number of pigs bought per hunter is used as the dependent variable, suggesting that the results are more to do with changes in wild pig densities than with changes in the number of hunters in an area (Table 4). Over the whole time-period, the number of pigs bought was highly significantly related both to the date of the transaction and to the time taken to drive to that location; the earlier in the time-period and the farther the drive, the more pigs were bought. In 1988, neither the date nor the time taken to get to the location were significant; in 1991–1994 the time taken was highly significant while the date was just non-significant, while in 1997 only the time taken to get to the location was significant. This strong effect of the time taken to get to a location on the number of pigs bought at that location is as expected if depletion of the resource is occurring along a spatial gradient. The lack of significance of the model in 1988 suggests that the resource may not have been severely depleted at that point. The mixed results for the effect of date give some indication of the timescale over which depletion was taking place—it was not significant in 1988 or 1997 (periods of 6–8 months), was just non-significant in 1991–1994 (a period of 31 months), and was highly significant over the whole 10-year period.

Evidence for population depletion in a given location in the short run will be conditioned to some extent on hunter behaviour. Hunters told us that when catch starts to reduce in an area, they first lay more snares in that area, then they shift between areas within the same hunting location, then they move location. This suggests that the short-run evidence for depletion may be more visible in increased hunter effort than in decreases in offtake, arguing for the importance of a complementary study of individual hunter behaviour. Nonetheless, the analysis of changes in the offtake per hunter over the entire study period shows clear evidence for resource depletion over space and time (Table 4).

Although changes in the number of pigs bought can be related to depletion of the resource, changes in the price paid to hunters are not so easily explained by the data. The data clearly show a step increase in both the mean price and its variability between 1994 and 1997 (Fig. 7). Hence we carried out regression analyses for the two periods separately (1988–1994 and 1997). These regressions have only weak explanatory power. They suggest that in 1988–1994, the only significant explanatory variable for price/pig received by hunters is the number of pigs sold at the same time (there is a lot of variability, but on average the hunters receive less per pig when selling in bulk), whereas in 1997, the price/pig obtained by hunters varies significantly with date and number of pigs sold at the same time, again with a lot of variability in the relationship (Table 5). The price the dealer pays to hunters does not vary with the time taken to get to a location (i.e. with the travel costs associated with buying the pig), or with characteristics of particular hunters (such as length of service or the number of pigs that the hunter has supplied in the past). Examining the data for individual hunters who supplied dealer X in more than one time period shows that the results are not caused by the differences in behaviour between new hunters in 1997 and hunters who had worked for the dealer over a long period—all the trends seen for the hunter group as a whole are mirrored amongst long-serv-

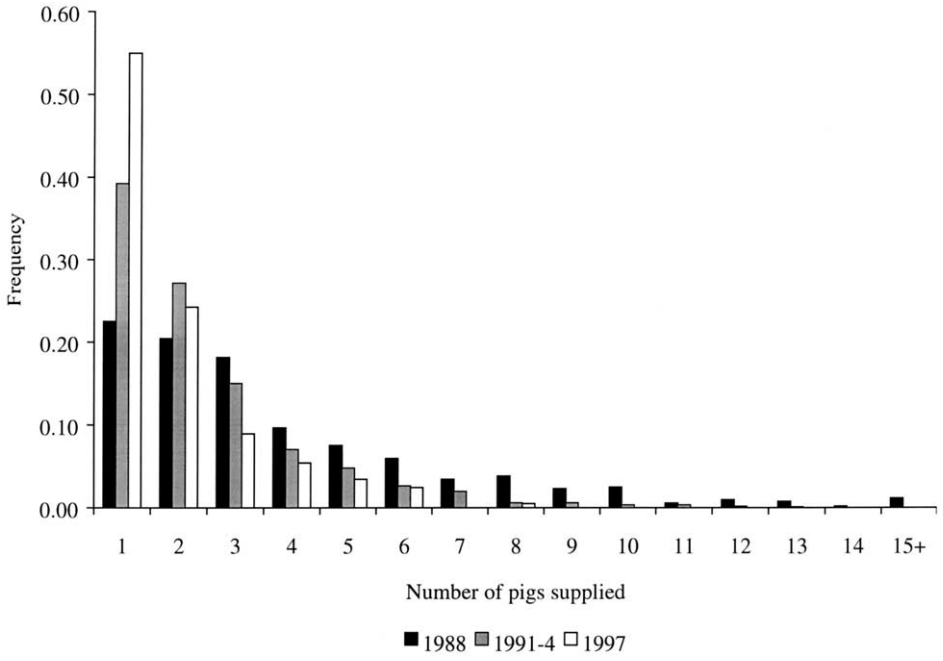

Fig. 6. Frequency distributions of the number of pigs supplied by individual hunters to the case study dealer on one trip, in 1988, 1991–1994 and 1997. In 1988, a single hunter could supply the dealer with more than 15 pigs at one time, while in 1997 the largest number of pigs supplied by a hunter at one time was 8.

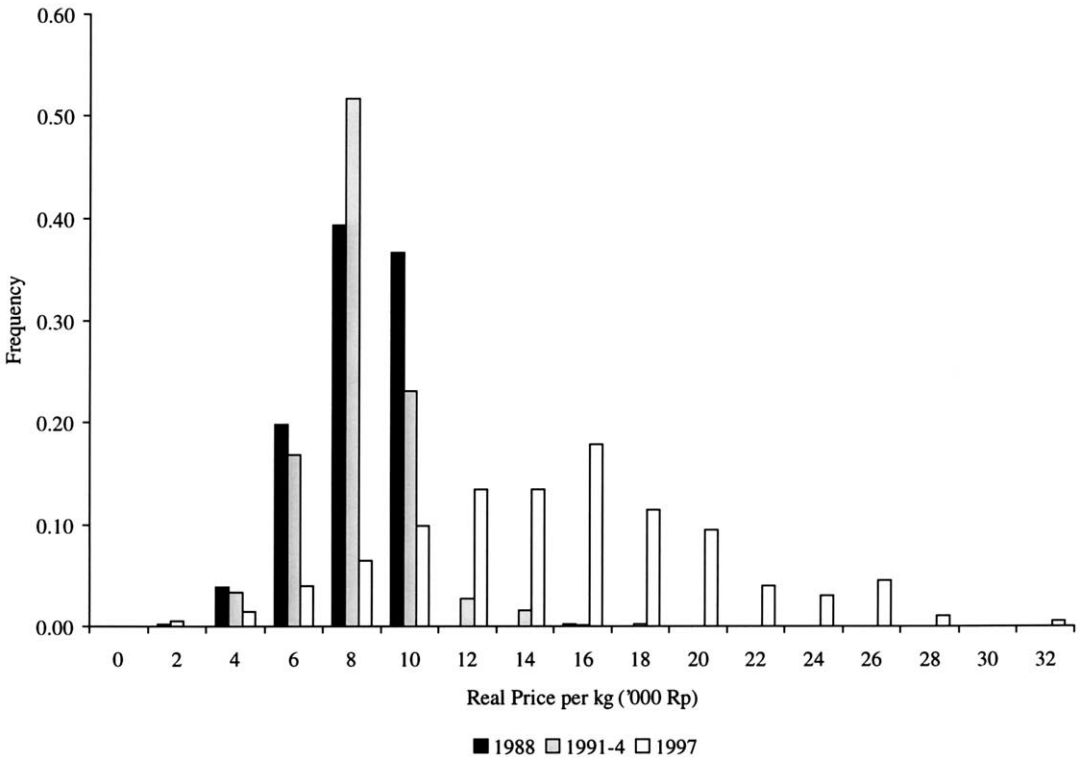

Fig. 7. Frequency distributions of the real price per pig (in Rupiahs deflated to January 1988) paid by the dealer to individual hunters for wild pig meat in 1988, 1991–1994 and 1997. The variation around the mean price increases with the mean price (1988: mean = 7051 Rp, S.D. = 385, Coefficient of Variation (CV) = 5.5%; 1991–1994: mean = 7189 Rp, S.D. = 1142, CV = 15.9%; 1997: mean = 13 740, S.D. = 2188, CV = 15.9%).

ing hunters. This suggests that individual hunters are very adaptable in their behaviour, moving long distances to hunt in new areas rather than remaining in an area that has become depleted.

The increase in mean price and its variability between 1988–1994 and 1997 could be caused by a number of factors, one of which could be changes in hunter behaviour. Anecdotal evidence from hunters and dealers suggests that since 1997, hunters have been less strongly bonded to particular dealers; they have started to sell their meat by the kg rather than as whole pigs, and are now prepared to sell meat to more than one dealer. This suggestion is supported by the data—the mean proportion of the dealer's trips met by a given hunter declined throughout the period, while the turn-over rate of hunters increased dramatically in 1997 (Table 6). This suggests that the rapid expansion of the wild pig meat market is leading to a much more competitive market at the hunter level. As with prices, the turnover rate changed between the second and third time periods, rather than being incremental, adding weight to the suggestion that there was a shift in hunter behaviour. Other observations, such as the reduction in the number of pigs sold per hunter (Table 3) and the increase in the number of hunters selling pigs (Table 6), are also likely to be related to these changes. However because we have data from only one dealer, it is difficult to clarify whether the apparent reduction in the number of pigs being sold to dealer X (overall and by individual hunters) is caused more by reduced catch rates or by hunters selling the same catch to more than one dealer.

4.3. Linking the dealer and the market

There are two periods for which data are available both for the case study dealer and for the market as a whole—15 months in 1993–1994 and 7 months in 1997. During these periods, dealer X generally sold wild pigs in Langowan market on Saturdays, the same day as our market surveys. Taking a monthly average, his pigs made up 38% of the total number of pigs on sale at Langowan in 1993–1994 and 30% in 1997 (the difference is non-significant; $t = 1.50$, $df = 18$). Although there were sales of wild pigs by dealers on other days of the week, and in other markets, dealer X clearly had a substantial market share in both time periods. Between the two periods, the real price of wild pigs in the market rose by 30%, while the number of wild pigs on sale fell by 23% (both ***; price: $t = -4.75$, $df = 7$; numbers: $t = 2.96$, $df = 20$).

The number of pigs that the dealer traded decreased between the two periods and the price in the market increased, but so did the price he paid to hunters in the forest. Although in 1997 the hunters supplied only 61% of the number of pigs supplied in 1993–1994, the real price that dealer X paid per pig rose by 86%, hence the average revenue per hunter rose by 38% (all *** in t-tests). These conflicting trends resulted in a non-significant drop of 25% in dealer X's revenues ($t = 1.94$, $df = 15$, two-tailed $P = 0.07$, NS). In order to get a true picture of the profitability of the trade, data on changes in costs are also required. Costs are available for the dealer in 1995 (Clayton et al., 1997), and showed that he was making substantial profits at that point. Since then, the costs of inputs such as petrol have risen considerably, which is likely to have led to an erosion of dealer X's profits.

Information from dealers suggests that the total number of dealers working in the province increased dramatically from about 12 in 1993 to 30 in 1996. Dealer X kept his market share in Langowan partly because the new dealers were more diversified in their trading behaviour. This included responding to changes in tastes in Minahasa; for example, at around this time people began to eat more domestic dogs, which dealers bought in the same areas as wild pigs. This diversification could in itself be a symptom of depletion of the wild pig resource, and has led to the total number of wild pigs on sale in Langowan market remaining relatively constant over time; similarly, although price increased between 1994 and 1997, it has since remained relatively stable (as would be expected if wild pig meat was substitutable with other meats on sale in the end market).

Table 4
Results of linear regressions of the number of pigs bought per hunter and total number of pigs bought in a location (both log-transformed), against the date on which the transaction occurred (date) and the time taken to drive to that location (time)

Variable[a]	Period	R^2	df	F	Model Sig[a]	Date beta[b]	Sig	Time beta	Sig
Total pigs	1988–1997	0.155	756	68.92	***	−0.468	***	0.312	***
	1988	0.007	143	0.507	NS	–	NS	–	NS
	1991–1994	0.098	509	27.59	***	−0.082	(*)	0.311	***
	1997	0.305	102	21.96	***	–	NS	0.554	***
Pigs per	1988–1997	0.147	756	64.84	***	−0.460	***	0.266	***
Hunter	1988	0.038	143	2.77	(*)	−0.167	*	–	NS
	1991–1994	0.084	509	24.23	***	−0.073	(*)	0.294	***
	1997	0.122	102	6.92	**	–	NS	0.333	**

Standardised betas (regression coefficients) are shown. Betas are not given if they are not significantly different from zero.

[a] The model is in the form $\ln(y) = \alpha + \beta_1 \text{Date} + \beta_2 \text{Time} + \varepsilon$, where y is either total pigs or pigs per hunter, α is the intercept, βs are the regression coefficients, ε is the error term.

[b] Significance: ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; (*) = $P < 0.1$, NS = $P > 0.1$.

Table 5
Results of multiple linear regressions relating the real price paid per pig to hunters by the case study dealer to a number of variables

Period	Variable[a]	Beta[b]	Significance[c]
1988–1994[d]	Intercept	7434.8	***
	Pigs	−62.9	***
1997[d]	Intercept	591 078.2	*
	Date	−16.1	*
	Pigs	−802.2	**

[a] Variables tested were: 'Date' date of the transaction; 'Pigs' total number of pigs supplied by the hunter in this transaction; Total number of transactions between hunter and dealer from the start of the time period to this date; Total number of pigs supplied by the hunter to the dealer from the start of the time-period to this date; Time taken to get the transaction location from the end market. These variables all appear highly significant in the regression for the entire period 1988–1997. The model is of the form $P=\alpha+\beta_1X_1+\beta_2X_2+\ldots+\varepsilon$, where P is the real price paid per pig, α is the intercept, βs are the regression coefficients, Xs are the explanatory variables, ε is the error term.

[b] Standardised betas (regression coefficients) are shown for the final models (which include only those variables with betas significantly different from zero).

[c] Significance: ***, $P<0.001$; **, $P<0.01$; *, $P<0.05$; (*) = $P<0.1$, NS = $P>0.1$.

[d] For 1988–1994 model: $R^2=0.008$, df = 1515, $F=11.62$, $P<0.001$. For 1997 model: $R^2=0.073$, df = 195, $F=7.58$, $P<0.001$.

5. Discussion

This study is one of the most thorough explorations of the wildlife trade that has been carried out, based on 10 years of highly detailed data, both from a case study dealer and from the market as a whole. As well as providing insights that could be useful for the conservation of the endangered babirusa, the study has been useful in highlighting more general issues for the study of the wildlife trade.

Since monitoring of the end-market was carried out regularly by a local shopper, it could be separated from our activities aimed at reducing illegal sales of meat from endangered species. Thus the study has been able to identify the effect of conservation interventions on the trade in an endangered species. The evidence suggests that law enforcement (particularly overnight checkpoints) had a dramatic short-term effect on the number of babirusas on sale in the market, but that over time, this effect was dulled by the dealers' refinement of their perceptions of the risks associated with these activities. However, the data also suggest that a generally heightened level of awareness among dealers may have led to a more sustained shift away from the sale of babirusa meat in the end-market (Fig. 4).

It is possible that rather than being due to changes in hunter or dealer behaviour, the observed step change in the number of babirusas on sale in the market in 1997 was due to a sudden non-linear decline in babirusa population size. Significant destruction of the babirusa's primary forest habitat is ongoing, both from commercial logging and smaller-scale clearance. This

Table 6
Changes in hunter behaviour between 1988 and 1997

	1988[a]	1992[a]	1997[a]
Number of trips made by dealer	29	30	24
Total number of hunters transacting with dealer	69	70	89
Mean proportion of trips met by a given hunter[b]	0.21	0.15	0.10
% of hunters serving at least 95% of the period[c]	11.6	11.4	1.1
Average length of service (% of total length of period)[c]	36.7	35.7	13.8

[a] The calculations were all carried out for the same 6-month block in each period (June–December 1988, 1992, 1997), so as to standardise the total time available.

[b] The mean proportion of trips met by hunters is significantly different between the periods (ANOVA test, $P<0.001$).

[c] Hunter turn-over rate is measured as the percentage of hunters supplying meat during at least 95% of the 6-month time period and as the mean length of time over which hunters supplied meat.

may well be a contributory factor in babirusa population declines. As Sulawesi Wild Pigs can use disturbed forests, habitat destruction would be expected to have a more severe impact on babirusas. Alternatively, non-linear population declines can be caused by interactions between hunter behaviour and prey ecology (e.g. through depensation). Establishing the causes and degree of any non-linear population decline would require data at the hunter level, babirusa population surveys and assessments of rates of change in habitat availability over time. But because of the very sudden change in numbers on sale at the market, it is quite unlikely that the observed pattern is entirely due to population decline.

Assuming that the drop in the number of babirusas sold in 1997 does relate to dealer behaviour, a key conservation question is what became of the babirusas that would have been sold in the end markets but were not, both in the short term as a result of particular law enforcement activities, and in the longer term because of a change in dealer perceptions. The possibilities include:

- A change in hunter behaviour (for example, laying snares in degraded forests where Sulawesi Wild Pigs, but not babirusas, are found), leading to a lower hunting pressure on babirusas. This would be ideal from a conservation perspective, but we have not found any evidence for this from discussions with hunters and dealers.
- Dealers discarding/failing to buy babirusas brought to them by hunters because of changes in the law enforcement environment. Although individual babirusas are still killed, this does at least reduce dealer and hunter profits, and provides pressure for a shift away from babirusa hunting.
- Dealers starting to sell more babirusas outside official markets (for example, at restaurants, from their homes or on the streets). This would be a problem, as it would compromise the monitoring programme, as well as indicating that babirusa hunting was likely to continue to be a conservation problem. From October 1999 we did observe a shift towards selling wild pigs away from the main market. The fact that we were aware of this shift when it did happen suggests that the data analysed here are likely to indicate a genuine decrease in the number of babirusas sold, but also brings into question the validity of future monitoring of the main markets, at least insofar as it concerns protected species.

It is very unusual to be able to obtain full records for a case study dealer, such as we have analysed here. These records have been very useful in highlighting the complexities of the trade. In particular, they show how difficult it can be to separate out evidence for resource depletion from the dynamics of the market itself. This distinction is very important for assessing sustainability and for planning suitable conservation interventions. Our 10-year dataset charts how the dealer has had to travel farther to buy wild pigs, how the price he paid per pig increased over time, and how the number of pigs bought per trip (both in total and per hunter) has decreased. These trends are all consistent with resource depletion. However, a more thorough assessment of the data suggests that it would be over-simplistic to interpret all these changes in the dealer's behaviour entirely in terms of depletion of the wild pig stock. Only increases in dealer travel time are likely to be unequivocally related to depletion. Otherwise, market dynamics are likely to be confounding any signal of depletion that might exist in the data on prices and quantities sold. Changes in the relationship between hunters and dealers affected the prices and quantities of wild pigs that hunters sold to the case study dealer during the study period. The fact that the end-market has a wide range of substitute goods on offer (in conjunction with the large profits still being made by dealers) means that end-market price is not a good indicator of depletion. It may be that the quantity of wild pigs on sale in the end market bears some relationship to levels of depletion, but this is very difficult to disentangle from changes in dealer behaviour caused by factors such as law enforcement or consumer tastes.

Carrying out a detailed study of one person's accounts has clarified how complex the influences on dealer behaviour are. This would not have been picked up by a standard trade survey con-

centrating on the end-markets. Similarly because we have done a long-term study, and one in which spatial data are included, we have found evidence of depletion through changes in location which a short-term or non-spatial study would not have found. Nonetheless, the study has major limitations. As in all long-term projects, we have been opportunistic in our data collection, and have started to collect new data as it has become apparent that they are necessary for a full understanding of the system. Hence our data are patchy, and analysis has shown that key elements are missing, some unavoidably. Issues that need to be addressed in similar future projects include:

- The fact that we had access only to one person's accounts means that we cannot be sure that the case study dealer is representative of the market as a whole, or that the changes in hunter behaviour that we inferred (such as switching between dealers) were actually taking place. We also could not estimate the degree to which dealers were diversifying into other goods. Even superficial data on the dealer population as a whole would have helped us to characterise the dynamics of the market as a whole with more confidence.
- The main drawback with the end-market data is that there are no data available on consumer incomes. This prohibits us from carrying out a full demand analysis, and means that we are unable to predict from our dataset how consumer behaviour might be affected by a change in the price of wild pigs, particularly as the economic and political crises since 1998 are likely to have affected incomes. This limits the value of the dataset for policy analysis.
- A major problem with the dataset from the case study dealer, a common feature of research into illegally traded goods, is that it is not possible to separate his trading into the component species. This is particularly serious in this case, because our previous work (Clayton et al., 1997) suggested that babirusa populations are likely to decline very rapidly when hunted along with Sulawesi wild pigs. This fact also means that aggregated data on the number of babirusas present in the end-market are not particularly informative in terms of actual patterns of depletion on the ground.

Perhaps the key lesson from our analysis, however, is that in order to understand the processes of resource depletion and separate them from market dynamics, it is imperative to obtain data on the catch, effort and hunting behaviour of individual hunters, together with population densities of the hunted species. Market data on the prices and quantities of species on sale reflect an amalgamation of many factors. These include population declines caused by hunting and habitat loss, market dynamics and changes in the perceptions and behaviour of the people involved (which may be brought about by conservation actions). In order to make effective conservation decisions we need to separate out these competing influences, because very different interventions are appropriate depending on which factors are causing the observed patterns in the prices and quantities of endangered species that are on sale.

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