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WILDLIFE FARMING: A VIABLE ALTERNATIVE TO HUNTING IN TROPICAL FORESTS?

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WILDLIFE CONSERVATION SOCIETY

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Young bearded pigs raised in a wildlife farm,
Sabal, Sarawak, Malaysia
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1. BACKGROUND

In many developing countries, wildlife is an essential food resource, a source of income for rural peoples, and an important part of human spiritual and cultural systems (Robinson & Redford, 1991; Hladik et al., 1993; Robinson & Bennett, 2000). In tropical forest regions, there is often little tradition of domestic livestock management; in regions without strong food production sectors, hunted wildlife can be essential for food security (Wilkie & Carpenter, 1999; Fa et al., 2003), or as a fall-back when other sources of food and income are scarce (Robinson & Bennett, 2002). Wild species commonly consumed in tropical forest countries include mammals, birds, reptiles, amphibians, and fish, as well as invertebrates such as termites, beetles, and snails. Forest peoples rely most heavily on terrestrial vertrebrates and fish for their livelihoods.

In recent years, concern has been growing about the unsustainable levels of wildlife hunting, especially in tropical forests (e.g., Robinson & Bennett, 2000; Milner-Gulland et al., 2002). Growing human populations, the introduction of modern hunting techniques, increased access to diminishing areas of forests, and increasing commercialization of hunting have all increased pressure on wildlife populations (Robinson & Redford, 1991; Robinson & Bennett, 2000). Recent estimates of annual wild meat harvest include 23,500 tonnes in the Malaysian state of Sarawak (Bennett et al., 2000), 67,000 to 164,000 tonnes in the Brazilian Amazon (Redford & Robinson, 1991), and one million tonnes in Central Africa (Wilkie & Carpenter, 1999). This is causing population declines and local extinctions of many species across the world's tropical forests (e.g., Bennett & Robinson, 2000), leading to questions of whether food security for tropical forest peoples is being compromised by the decline in the wildlife resource. Theoretical calculations for Central Africa project that, at present harvest rates, the protein supply from bushmeat will drop by 81 percent over the next 50 years (Fa et al., 2003). Alternative sources of protein are required to ensure both that people have a long-term source of protein, and that wildlife species are conserved.

One solution often proposed is to farm wildlife species for their meat (e.g., Cicogna, 1992). This would allow people to eat wild meat, while taking pressure off wildlife populations. The solution is controversial, however, with concerns about the viability of such farming, its cost effectiveness, and its impact on wildlife populations (e.g., Emmons, 1987; Fa, 2000). This paper, therefore, examines the viability and conservation role of wildlife farming in tropical forest countries. It focuses on farming of wild terrestrial vertebrates, where the primary motivation is to provide protein for local people's consumption to take pressure off wild populations. Savannah ranching, aquaculture, farming with the primary aim of producing skins and hides, and export-based wildlife farming are not considered here.

Wildlife farming proponents envision fully-controlled production systems, independent of wild populations for source animals, operating in urban, peri-urban, and rural settings to supplement human protein intake without large investment costs (Cicogna, 1992). Farming a wide range of animals, including tropical forest species, has been proposed since the 1950s in response to food security concerns (de Vos, 1977; Ntiamoa-Baidu, 1997). Despite these historical origins, wildlife farming has not become widespread in Africa, Latin America, or Asia, and today few wild vertebrate species native to the humid tropics are commonly farmed for protein (Fa, 2000). The most notable exceptions are rodents in parts of West and Central Africa (Mensah, 2000).

The lack of advancement notwithstanding, the concept of wildlife farming continues to be proposed as a solution to the supply of hunted wildlife being unable to meet the demand. A wide array of vertebrate species has been investigated for farming to obtain meat (Appendix 1), some because, when hunted, are preferred food species (Smythe & Brown de Guanti, 1995), others because they command a high price in markets (Jori et al., 1995).

Raising wild species for food does not necessarily comprise domestication of the species. Domestication is a long and intensive process whereby humans selectively control the animals' reproduction, with resulting genetic changes (Box 1).

Many factors determine the feasibility of raising a species in captivity, including the species' biological parameters, such as productivity and vulnerability to disease, and the cost-effectiveness of farming it. Conservation issues to be considered include demands on source populations, genetic mixing with wild populations, potential introductions of invasive alien species, and law enforcement issues. Socio-cultural issues also influence the likely success of such efforts. This paper will consider all of these factors, to assess under which conditions wildlife farming of tropical forest species might, and might not, be feasible.

Box 1: Definitions

People obtain protein and other resources from terrestrial vertebrates in a variety of ways, ranging from hunting wild animals to the harvesting of domesticated species (Redford et al., 1995). Between hunting and domestication, herding, ranching, and farming systems occur along an axis of increasing confinement. Each system is defined below, based on Hudson's (1989) categories for ungulates.

Hunting: the harvest by any means of wild animals for subsistence, commercial or recreational purposes.

Herding: systems in which animal distributions are critically controlled by behavioral modification, such as luring, habituation, and taming. No physical barriers to animal movement are involved.

Both ranching and farming are systems that restrict animal movements with physical barriers. Containment systems form a gradient from extensive to intensive husbandry, with ranching at one end of the continuum and farming at the other.

Ranching: management of populations that are fenced but otherwise managed as wild animals. Ranching allows ownership of individual animals by an enterprise, an important departure from hunting. An assemblage of different species may be raised together. Ungulate ranching is very developed in eastern and southern Africa.

Farming: the intensive husbandry of wild animals in confinement, which can involve supplementary feeding, habitat manipulation, and veterinary treatment. Animals may be bred, raised to required weights, and then exploited for consumptive use. In some cases, farming systems may involve harvesting young or eggs from the wild and then raising individuals to maturity. Farming is practiced in this manner with some reptile species, including iguanas and crocodiles (Redford et al., 1995). The term semi-domestic has been used in describing farming to acknowledge that taming or farming a wild animal does not make it domesticated (Ntiamoa-Baidu, 1997).

Domestication: There is no single, clear definition of domestication in the biological, agricultural, or archeological literature. A widely-cited definition of domestication is provided by Eltringham (1984), where domestic animals are defined as those that breed readily in captivity and whose owners have some control over their reproduction. Domestication also involves biological changes, with the stock being selected away from the wild type (Clutton-Brock, 1987). Domestication is a lengthy and gradual process, with a long history. The first origins of domesticated animals go back approximately 12,000 years. Scientists traditionally believed that domestication coincided with the transition from a hunter/gatherer lifestyle to more settled agricultural way of life, but new evidence demonstrates that animal domestication may have preceded agriculture (Zeder & Hesse, 2000). Domestication appears to have been a fluid process, with humans gradually domesticating animals through herd management, controlling animal movements and then sex ratio and age structure of the populations through offtake. The anatomical changes that mark domestic species emerged after there was sufficient breeding isolation from wild populations (Marean, 2000).

2. BIOLOGICAL CONSIDERATIONS

2.1 Phylogeny

2.1.1 Social behavior

A species' social behavior affects the ease with which it can be kept in captivity. For economically profitable production, social gregariousness is essential because animals must be housed in groups. Pacas (*Agouti paca*), for example, are territorial, and highly intolerant of individuals outside the male-female pairbond, so rearing them in farms is problematic (Box 2).

Stress-related trauma remains a major cause of death of some species in captivity.

Tolerance of human presence is also required to feed and handle animals. Both social gregariousness and adaptability to human presence can be increased in some species through intensive selective breeding programs (Box 2) and daily human handling (Smythe, 1991; Smythe & Brown de Guanti, 1995; Trut, 1999). Nonetheless, stress-related trauma remains a major cause of death of some species in captivity (e.g., cane rats, *Thryonomys swinderianus*), possibly depressing reproduction, leading some to recommend dosing the animals with a long-acting neuroleptic to suppress stress-related behavior (Adu et al., 1999).

Box 2: A case study of pacas in captivity

The paca (*Agouti paca*) is a nocturnal, hystericomorph rodent, frequently proposed as a candidate for wildlife farming because of its popularity as a food source in Latin America. Its social behavior, dietary needs, and reproductive output, however, are not conducive to captive rearing. Wild pacas are territorial, monogamous, and socially intolerant outside the male-female pairbond (Emmons, 1987). Pacas are frugivores, and must be fed on local produce and fruits, produced or collected through human labor. These traits make paca farming unrealistic and unprofitable (Emmons, 1987). Although pacas are kept in captivity in Latin America, the animals are rarely bred in captivity, but more frequently are wild-caught when young and then raised until they can be consumed.

An experimental research program at the Smithsonian Tropical Research Institute in Panana attempted to domesticate pacas from 1983 to 1990, using critical-period learning similar to imprinting (Smythe, 1991; Smythe & Brown de Guanti, 1995). Researchers succeeded in raising pacas in captivity from birth, and selecting for tameness and gregariousness, so that several females could be kept in groups with one male. Thus, the seven-year program succeeded in creating a line of tamed, sociable animals, which could be distributed to start other captive colonies.

The gestation period of 157 days is relatively long for a mammal of this size, however, and the program did not increase the number of offspring per birth from one; although selective breeding for females that bear twins was proposed, this has yet to be achieved. Thus, paca rearing is not considered profitable enough to recoup the necessary expenditures on infrastructure, unless compensated for by a high market price (Smythe, 1991; Smythe & Brown de Guanti, 1995). Paca meat might fetch a higher price than domestic meat, but when the overall costs and uncertainty of the future product are taken into account, the species remains a precarious investment choice for the livestock farmer (Godoy et al., 1998).

2.1.2 Energy requirements

Suitable food must be readily and economically available to meet a species' energy requirements. Frugivores (e.g., some civets, flying foxes) are relatively costly to rear in captivity because they need to be fed either purchased or collected fruits, requiring considerable cost or time to procure. Secondary consumers (e.g., some species of turtles) must be fed animal protein, and may consume more animal protein than they produce, which is rarely cost effective. In contrast, herbivorous species that eat browse or grasses can more readily be fed economically. Hence, most species which have been domesticated for human consumption require food that can be produced cheaply and easily. Most such foods are not directly consumed by humans since our digestive systems are not adapted for digesting such plant foods (Emmons, 1987), so we are not competing for food with these species.

Because domestic animals have been selectively bred for high productivity over thousands of years, even wild species with high reproductive rates are generally less productive than domestic animals.

2.1.3 Reproductive rates

Species selected for wildlife farming must have high reproductive output to produce meat at an economically viable rate. Reproductive output is a factor of time to sexual maturity, litter size, length of interbirth interval, and age of last reproduction (Redford et al., 1995). For example, the African brush-tailed porcupine (*Atherurus africanus*) was thought to be a good candidate for wildlife farming, but little was known about this species. Further research revealed that brush-tailed porcupines do not attain their adult weight for almost two years, and females produce only one offspring per birth (Jori et al., 1998; 2002). Thus, the species is no longer considered a good candidate for farming. Similarly, the large flying fox (*Pteropus vampyrus*) breeds so slowly that it is uneconomical to farm it (Box 3).

Within limits, the time to sexual maturity can be decreased with the provision of abundant, high-quality food. The number of offspring per litter cannot be changed easily, if at all, however. In particular, species that have only one offspring per birth are confined to this level of production. Attempts to breed pacas to produce more than one offspring per litter have not yet proven successful (Box 2). Even among well-studied domestic cattle, intensive research in genomics, combined with new technologies such as artifical insemination, embryo transfer, and cloning, will be required if cattle are to have twin litters with any meaningful frequency (Rohrer, 2004).

In addition, because domestic animals have been selectively bred for high productivity over thousands of years, even wild species with high reproductive rates are generally less productive than domestic animals. For example, cane rats (*Thryonomys swinderianus*) are one of the most prolific wild species proposed for captive breeding. Cane rats produce four to six offspring per litter, compared to seven to eight for the domestic rabbit, and have a gestation period of 153 days compared to the rabbit's 32 days (Demeterora et al., 1991).

2.1.4 Growth rates

Meat output is determined, in part, by the rate of growth to suitable slaughter weight. Within limits, growth rate can usually be increased with better nutrition. Adult body size also affects growth rate. Small and large animals may be

Box 3: The productivity of the large flying fox (*Pteropus vampyrus*) and its potential for captive breeding

From Gumal et al., 1998.

The large flying fox (*P. v. natunae*) is a species of conservation concern in Sarawak, Malaysia, due to loss of habitat and, especially, overhunting. Compared to sympatric mammals of similar body size, the flying fox has low reproductive capacity and growth. Starting with an initial single breeding pair each of flying foxes and Norway rats, with zero mortality, by the end of a year there would be three flying foxes and about 4,000 rats.

Reproductive parameters of *Pteropus* and *Rattus*

	Pteropus	*Rattus*
Gestation length (days)	140-192	21-30
Litter size	1	8
Interbirth interval (days)	180-360	28
Maximum litters per year	2	13
Age of sexual maturity (months)	18-24	3-5
Maximum life expectancy (years)	31	4

Because of its low biological productivity, it is not economically feasible to farm *P. vampyrus* in captivity. A model was generated with the following assumptions: (i) the initial breeding stock is 1,000 animals, with a female to male ratio of 4:1; (ii) according to Sarawak's wildlife laws, only second generation animals (F2) are traded; (iii) the survival rate of wild-captured animals (F0) in captivity is 90%; (iv) each female produces one offspring per year; (v) sexual maturity is reached at 2 years; (vi) survival of young until breeding is 100% for males and 75% for females; (vii) survivorship of pups is 100%; (viii) excess first generation (F1) males are destroyed; (ix) all F2 animals are sold as juveniles; and (ix) maintenance costs are $0.13/animal/day including food and veterinary costs. Thus, survivorship and reproduction rates are optimistic. Even with such assumptions, and if each 500g animal was sold for $81 (which is prohibitively expensive for most people in the rural tropics), producers would only break even after 16 years.

f = female; m = male.

Year	F0 (f/m)	F1 pups (f/m)	F1 yearling (f/m)	F1 breeding (f/m)	Total breeding	F2 Sale-able	Feed Costs	Income	Profit (loss)
1	800/200	400/100	0	0	1500	0	($72636)	$0	($72,039)
2	720/180	360/90	400/100	0	1850	0	($89,584)	$0	($89,584)
3	648/162	324/81	360/90	400/100	2165	400	($104,838)	$40,749	($64,089)
4	583/146	292/73	324/81	720/180	2399	720	($116,145)	$73,347	($42,797)
5	525/131	262/66	292/73	972/243	2564	972	($124,142)	$99,019	($25,123)
6	472/118	236/59	262/66	1166/292	2672	1166	($129,378)	$118,823	($10,555)
7	425/106	213/53	236/59	1312/328	2733	1312	($132,326)	$133,676	$1,350
8	383/96	191/48	213/53	1417/354	2755	1417	($133,390)	$144,370	$10,980
9	344/86	172/43	191/48	1488/372	2745	1488	($132,918)	$151,588	$18,670
10	310/77	155/39	172/43	1531/383	2710	1531	($131,207)	$155,919	$24,712
11	279/70	139/35	155/39	1550/387	2654	1550	($128,509)	$157,868	$29,359
12	251/63	126/31	139/35	1550/387	2582	1550	($125,038)	$157,868	$32,830
13	226/56	113/28	126/31	1534/384	2498	1534	($120,976)	$156,290	$35,313
14	203/51	102/25	113/28	1506/377	2405	1506	($116,477)	$153,448	$36,971
15	183/46	92/23	102/25	1469/367	2306	1469	($111,667)	$149,612	$37,944
16	165/41	82/21	92/23	1423/356	2203	1423	($106,655)	$145,008	$38,354
17	148/37	74/19	82/21	1373/343	2097	1373	($101,528)	$139,830	$38,301
									Net profit: $0

equally good at assimilating food and producing protein, but small animals produce protein faster than do large animals due to the formers' higher metabolism. One ton of rabbits and one ton of cattle can eat the same amount of food, produce the same amount of waste, and produce the same amount of new tissue, but rabbits will accomplish this in three months, while cattle will require fourteen months (Peters, 1983).

2.1.5 Space requirements

Species that require large amounts of space in captivity are not appropriate for production systems if space is limited. Animals housed at inappropriately high densities experience increased stress, greater susceptibility to disease, and display aberrant social behavior, which combine to decrease production. Even for chickens, which can be raised in relatively confined spaces, high-density cages cause increased stress, which is reflected in decreased production (Craig & Muir, 1998).

2.1.6 Nutritional benefits

Studies comparing nutritional benefits of wild animals and domestic livestock have generally found them to be comparable (Ntiamoa-Baidu, 1997). While wild animals are sometimes considered leaner or to have higher vitamin content (Ntiamoa-Baidu, 1997), these measurements often come from wild-caught animals. Adaptation to a captive lifestyle and supplied diet alters an animal's nutritional value. Meat from wild species in captivity, therefore, is probably similar in its nutrient value to that from domesticated species.

In some cases, farming programs continue to draw from wild populations for source animals long after the initial captive population is established.

2.2 Demands exerted on source populations

The initial founder stock for captive wildlife populations must originally be taken from the wild. In some cases, farming programs continue to draw from wild populations for source animals long after the initial captive population is established. Over 90 percent of cane rat farmers in Ghana depend on wild stock for breeding animals, and founder animals only represent a portion of those captured for farming because of initial high mortality rates due to trauma during capture (Asibey & Addo, undated). The unavailability of breeding stock is considered the primary obstacle to expansion of cane rat farming in Ghana (Adu et al., 1999).

In addition, animals from wild populations sometimes continue to be collected, even after the establishment of a captive population, to improve performance or hardiness of the farmed animals through interbreeding.

The result is that establishment of captive facilities can be an ongoing drain on wild populations. The removal of Siamese crocodiles (*Crocodylus siamensis*) from the wild for farming has led to local extinctions of the species throughout parts of its range.

2.3 Disease

Animal health and disease are key concerns in all livestock farming, and awareness of the tight links between domestic animal, wildlife, and human health have increased in recent years (Daszak et al., 2000; Karesh et al., 2005). Disease is a concern when farming wild species because of the limited veterinary knowledge about wild animal diseases, and how disease in these species in captivity interacts with wild populations, domestic animals, and people. Unknown infectious diseases could become apparent after species are taken into captivity, and wild animals in captivity are also vulnerable to diseases passed from domestic animals (Cooper, 1995). Little research has been conducted on disease transmission surrounding captive wildlife in tropical forests, however (Hardouin, 1995).

Intensive farming concentrates diseases into a small area, thereby allowing rapid amplification and spread of any diseases within the captive population.

High-density captive conditions can have serious ramifications for the health of both wild and captive populations. Intensive farming concentrates diseases into a small area, thereby allowing rapid amplification and spread of any diseases within the captive population. Captive populations may also allow for the rapid mutation of disease, and serve as a reservoir for diseases, which can potentially spread to wild populations of the same or other species in surrounding areas. For example, initial surveys in Bolivia found that one-half of all brocket deer and one-quarter of all peccaries had been infected with leptospirosis, a bacterium that causes major, sometimes fatal, health problems in all mammals, including humans (Wildlife Conservation Society, 2003). Proposals to take deer or peccaries into captivity must consider the effects of leptospirosis on the anticipated productivity of farmed wildlife, as well as the potential consequences on human and livestock health.

The best-known examples of disease interactions between domestic livestock, wild animals, captive wildlife, and humans are from North America, a temperate, not tropical, ecosystem but one which has been well studied, and thus can shed light on tropical wildlife farming. Chronic Wasting Disease (CWD) is a transmissible neurological disease of deer and elk (*Cervus elaphus*) that has spread primarily through the movement of farmed animals (Box 4).

Box 4: Chronic wasting disease (CWD) in captive and wild North American cervids

CWD is a fatal, transmissible, neurological disease in deer and elk. It produces small lesions in the brains of infected animals, and is characterized by loss of condition and behavioral abnormalities. CWD is a transmissible spongiform encephalopathy (TSE), or prion disease, and is similar to mad cow disease in cattle and scrapie in sheep.

Although the origin of CWD is unclear, it was first recognized in a captive deer population in Colorado in the 1960s. The disease may reach very high prevalence in captive populations. In one infected research facility, more than 90 percent of mule deer (*Odocoileus hemionus*) resident for greater than two years died or were euthanized while suffering from CWD (Williams et al., 2003). Captive populations of cervids and the movement of farmed animals in commerce has been primarily responsible for spreading CWD. In several areas of the US and Canada, the transmission of CWD from captive populations to wild populations has probably occurred (Williams et al., 2002).

Attempts to control and monitor CWD are expensive and time-intensive. Federal compensation for elk farmers in Saskatchewan that were mandated to destroy their stock has reached $24,000,000 (Wildlife Conservation Society, 2003).

CWD has been diagnosed in game farms in Wyoming, Minnesota, Wisconsin, New York, South Dakota, Nebraska, Oklahoma, Colorado, Montana and Kansas in the US, and Alberta and Saskatchewan in Canada. In the wild, CWD is found in Utah, New York, South Dakota, Colorado, Nebraska, Wyoming, Illinois, New Mexico, Wisconsin, and Saskatchewan (http://www.cwd-info.org).

Bovine tuberculosis also affects wildlife, livestock, and captive cervid herds in the US. It is spread primarily by close contact with infected animals, so is exacerbated by the crowding and stress found under the high-density conditions of livestock and cervid farming.

In response to the close links between wildlife, livestock, and human health, in 2001 the Wildlife Disease Association and the Society for Tropical Veterinary Medicine issued the Pilanesberg Resolution, which calls for the recognition of animal health science as critical to the design and management of wildlife and livestock-based programs (Gibbs & Bokma, 2002). Although those proposing wildlife farming have noted potential issues with human and wildlife health (Cooper, 1995; Hardouin, 1995), farmers working with wild species might not have access to appropriate extension workers or health professionals, including veterinarians (Jori et al., 1995). Veterinary facilities and health regulations are limited in some tropical countries, and can be beyond the financial means of many rural peoples.

2.4 Genetics

Interbreeding between wild and captive populations of the same or closely related species can potentially pass deleterious genetic traits to wild animals (Jori et al., 1995). Farmed animals are often selectively bred for a specific set of traits, including fast growth rates, large adult size, and high reproductive production in females. Escapes of farmed animals pose the possibility of their interbreeding with wild animals and altering the genetic make-up of wild populations. All efforts to ensure that captive wildlife species do not escape are crucial, as is an evaluation of any populations of the same or similar wild species nearby which might present the possibility of interbreeding (Cooper, 1985).

Interbreeding between wild and captive populations of the same or closely related species can potentially pass deleterious genetic traits to wild animals.

Interbreeding between some species in captivity can create hybrid animals, as seen in Asian turtles. Hybrid turtles are bred in farms, passed off as highly prized, rare species which they resemble, and are sold for medicine, food, and private collections. Hybrid turtles have even been described as new species, obfuscating turtle taxonomy and conservation efforts (Dalton, 2003).

3. ECONOMIC CONSIDERATIONS

3.1 Farming wildlife versus hunting

Where wild animals are readily available, and hunting is low-risk without a significant threat of fines or incarceration, hunting an animal costs less than raising it in a farm. In many parts of the humid tropics, the costs of obtaining protein through hunting are low. Hunters only pay for the costs of bullets or snares, the effort which they expend on hunting trips, and the opportunity cost of their time if hunting decreases income that could have been earned through other means. If wildlife is "free for the taking", hunting is generally easier, faster, and cheaper than farming wildlife (Gumal et al., 1998). Wildlife farming is only likely to be widely embraced, therefore, if production costs and efforts are lower than hunting (Ntiamoa-Baidu, 1997; Wilkie & Carpenter, 1999), or if hunting incurs significant penalties which outweigh the possible gains. Laws controlling at least some aspects of hunting exist in many developing countries, and enforcement of such laws would increase the potential costs to the hunter, through potential fines or incarceration. In many countries across the humid tropics, however, enforcement of hunting laws is weak or non-existent, (Bennett et al., 2000). Moreover, the laws of many countries provide exemptions for subsistence hunting in rural areas. Returns from hunting are immediate, with the wild meat being consumed or sold as soon as it is hunted.

For wildlife farms to be a conservation tool, external investments and incentive systems are required together with parallel disincentives against hunting.

By contrast, wildlife farming requires substantial investments of time and money. The costs of even small-scale wildlife farming may still be significant for the poor, remote, or landless people often envisioned as wildlife farmers (Smythe, 1991; Hardouin, 1995; Smythe & Brown de Guanti, 1995; Ntiamoa-Baidu, 1997). Most systems of keeping wildlife in captivity require an initial capital investment in infrastructure to hold the animals. Wire fencing, concrete, or cage materials may be prohibitively expensive for farmers. The time and costs of transporting infrastructure materials into remote areas are often extremely high. There might be less expensive alternatives, such as mud walls to fence cane rats (Ntiamoa-Baidu, 1997) and deeply buried wood poles to contain pacas (Roan McNab, personal communication), but considerable time is still required to build and maintain infrastructure. Additional economic expenses also include feeding, health monitoring and treatment, and the farmer's time. Returns from farming are long-term, sometimes requiring several years of investment before significant returns are forthcoming.

It is generally more cost-effective to hunt wildlife than to farm it, until the point when local wildlife populations have largely been extirpated. Thus, for wildlife farms to be a conservation tool, external investments and incentive systems are required together with parallel disincentives against hunting.

3.2 Farming wildlife versus domestic livestock

To be economically attractive, wildlife farming would have to offer returns per unit investment equivalent to rearing domestic species. This is generally not the case, due to the the low productivity of many wildlife species compared to domesticated ones (Section 2.1.3; Box 2; Box 3).

The general lack of experience in raising wild species also make these farms riskier than raising domestic animals. Production for cane rats is more complicated than that of domesticated livestock (Jori et al., 1995). Asking marginalized farmers in developing countries to expend considerable amounts of time, energy, and capital on untried systems is unlikely to succeed (Eltringham, 1984). Finally, slaughter and processing requirements of wildlife species are less likely than domestic species to meet national health and hygiene regulations in many countries (Rushton et al., 2004).

Asking marginalized farmers in developing countries to expend considerable amounts of time, energy, and capital on untried systems is unlikely to succeed.

4. LAW ENFORCEMENT CONSIDERATIONS

Farms can be a mask for laundering illegal trade of wild-caught animals.

Farms complicate enforcement of laws concerning hunting and trading of wildlife. Without substantial enforcement capacity, including chain of custody, enforcement officers are unable to determine the provenance of animals in urban markets. Also, farms can be a mask for laundering illegal trade of wild-caught animals. This is true globally, but is especially a concern in much of East and South-east Asia where wildlife farms are being adopted as a way to provide wildlife for food and medicines in the face of vast and escalating demand which greatly exceeds any potential supply from the wild (e.g., Wildlife Conservation Society and TRAFFIC, in press). Yet it is also a region where much of the trade is through major, highly organized illegal networks, and farms are one potential way to pass wild-caught animals off as captive-bred ones, unless the legal framework for farms is strong, and enforced. In much of the region, as elsewhere in the humid tropics, enforcement capacity is inadequate to allow for this, so the increasing number of farms presents a major and possibly insuperable challenge for law enforcement.

At international level, species listed on Appendix I by the Convention on International Trade in Wild Species of Flora and Fauna (CITES) cannot be commercially traded internationally, unless they are captive bred which qualifies them to be traded as Appendix II species. Captive-bred animals of species listed on any CITES Appendix can only be granted a CITES permit for international trade if the breeding facility is certified by the CITES Secretariat. To ensure that only captive-born animals are sold, CITES prohibits the sale of animals taken from the wild and their offspring (F1). This prevents the practice of capturing pregnant females from the wild and selling the progeny. Thus, only second generation (F2) animals can be sold under CITES. CITES has many regulations and procedures to ensure compliance.

CITES policy on captive bred animals forms the basis for national legislation in some cases. For example, Sarawak law states that wildlife farms can only sell F2 animals (State Government of Sarawak, 1998).

5. INVASIVE ALIEN SPECIES CONSIDERATIONS

Invasive alien species are "species introduced deliberately or unintentionally outside their natural habitats where they have the ability to establish themselves, invade, outcompete natives and take over the new environments. They are widespread in the world and are found in all categories of living organisms and all types of ecosystems.... The threat to biodiversity due to invasive alien species is considered second only to that of habitat loss. They are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity.... Invasive alien species can cause significant irreversible environmental and socio-economic impact at the genetic, species and ecosystem levels. Their management costs include not only costs of prevention, control and mitigation, but also indirect costs due to impacts on ecological services" (Convention on Biological Diversity: http://www.biodiv.org/programmes/cross-cutting/alien/default.asp).

Wildlife farming on a significant scale almost inevitably results in animals eventually escaping. If the species is not native to the local area, escapees pose potential threats to local species, and the wider environment (Parker et al., 1999; Mack et al., 2000; Pimentel, 2002). The Convention on Biological Diversity recognizes "game ranching" as a possible means of introducing invasive alien species, and calls for environmental impact assessments and adoption of a precautionary approach when planning such developments.

The species most suitable for productive farming are those with fast growth and high reproductive potential: the same characteristics which can enable populations of these species to grow explosively in the wild, at which point they are defined as "invasives". Invasive species can cause ecological disruption and threaten native species if they can successfully establish in the new area. For example, Chinese soft-shelled turtles (*Pelodiscus sinensis*) which have escaped from farms in Malaysia are reportedly out-competing the slower-breeding and less aggressive native turtles. Coypus (*Myocastor coypus*) which escaped from fur farms in Britain were responsible for widescale local extinctions of the native European otter (*Lutra lutra*). Invasive species may also introduce exotic diseases and parasites that threaten native fauna and domestic livestock (Daszak et al., 2000). For example, avian malaria was brought into Hawaii via exotic pet birds, and devastated native bird populations.

Wildlife farming on a significant scale almost inevitably results in animals eventually escaping. If the species is not native to the local area, escapees pose potential threats to local species, and the wider environment.

6. SOCIO-CULTURAL CONSIDERATIONS

Hunting often continues even when farmed substitutes are available.

Throughout the humid tropics, especially in rural areas, hunting often continues even when farmed substitutes are available, because:

(i) When wildlife is still relatively abundant, it is the cheapest way to obtain meat (Ojasti, 1997; Section 3.1). Many of the people most dependent on wild meat are the poorest and most marginalized in a country, so would be unable to afford the capital outlay necessary for any farming schemes (Rushton et al., 2004);

(ii) Farmed animals are often viewed primarily as savings and insurance, rather than protein sources to be used routinely (Wilkie & Carpenter, 1999; Robinson & Bennett, 2000). This applies to domesticated animals, and given the investment in keeping them, is also likely to apply to farmed ones;

(iii) Many cultures in the humid tropics have little tradition of long-term planning and livestock management, especially the most remote peoples, and overcoming this is likely to take long-term extension programs. For example, when the government provided the Penan people in Sarawak with chickens intended for breeding, the Penan either ate the animals before they could breed, or treated them as pets and did not eat them (M.T. Gumal, personal communication);

(iv) Obtaining meat is not the only reason for hunting. Acquisition of animal trophies as cultural artifacts or for personal adornment (e.g., feathers, skins, teeth) is a widespread practice throughout tropical forest regions. Many artifacts are from animals which would not be farmed for their meat (e.g., hornbills, birds of paradise, large carnivores);

(v) Animals hunted in the wild are frequently regarded as having medicinal properties, or have particular symbolic or social importance, e.g., in the naming of children. Such values are unlikely to be present in farmed wildlife (Archetti, 1997);

(vi) Some cultures have no concept of or belief in natural resource scarcity (Croll & Parkin, 1992), which may decrease motivation for generating protein and income through wildlife farming;

(vii) Hunting itself is of major cultural importance throughout the humid tropics. To be a hunter is essential in gaining respect, achieving manhood, or winning a bride (Bennett & Robinson, 2000). This is not achieved if the wildlife is captive-reared;

(viii) In most tropical cultures, hunting is the role of men, and raising livestock often falls to the women (Kleyson, 1996; Archetti, 1997), so one is not a substitute activity for the other. In Sarawak, for example, fish farming did not reduce hunting, but women instead generated income from fish farming while men continued to hunt; tourism produced similar income to fish farming and did reduce hunting since it occupied the men's time (A. J. Nyaoi and E.L. Bennett, unpublished data).

As a result, people in tropical forests hunt, even when they have alternative sources of nutrition and income (e.g., Sulawesi: Lee, 2000; India: Mahdusudan & Karanth, 2000; Congo: Eves & Ruggiero, 2000; Paraguay: Hill and Padwe, 2000; Mexico: Jorgenson, 2000). Provision of alternative protein alone, whether from farmed wild or farmed domesticated species, is unlikely to reduce hunting in many areas. Preventing people from hunting unsustainably is impossible, however, unless alternatives are available. Thus, increasing alternative protein must be seen as one component in a multi-faceted conservation program that also includes strong education and enforcement components.

Provision of alternative protein alone, whether from farmed wild or farmed domesticated species, is unlikely to reduce hunting.

7. SUMMARY AND RECOMMENDATIONS

Wildlife farming is complex, combining aspects of rural development, agricultural production, and conservation. It has received increasing attention in recent years as over-hunting has become an increasing conservation concern, and as food security has become a major development concern, especially in Central Africa.

In the humid tropics, all available data and information strongly indicate that wildlife farming to produce meat is not economically viable compared to hunting or to farming of domestic species. Thus, it is not the optimal way to ensure food security, due in large part to the slow productivity, and social and space requirements, of most wild species. Wildlife farming also poses major conservation threats to existing wildlife populations in the area of the farm, due to the need to acquire the breeding stock from wild populations, increased risks of disease and genetic contamination of wild populations of the same or other species, risks of the spread of invasive alien species including diseases, and wildlife farms being a front for illegal trade of wild-caught animals. Moreover, until wildlife numbers in the wild become so low that it is no longer worthwhile hunting them, wildlife farming is unlikely to reduce hunting, due to the high costs of farming compared to hunting, lack of appropriate technical skills and funds, and cultural constraints. Thus, wildlife farming is not the panacea to solve the problems of food security and unsustainable hunting in the humid tropics as is sometimes proposed.

Research and funding should be directed towards improving domestic animal stock, creating hardier breeds that are less susceptible to the diseases that have plagued domestic livestock in the humid tropics in the past.

Instead, research and funding should be directed towards:

- improving domestic animal stock, creating hardier breeds that are less susceptible to the diseases that have plagued domestic livestock in the humid tropics in the past;
- establishing major extension and education programs;
- determining the most appropriate locations and socioeconomic strategies for expanding domestic livestock farming as part of planning for a sustainable landscape (Robinson, 1994), so people's nutritional and economic needs are met, the loss and degradation of habitat often associated with hoofed animals is avoided, and areas of conservation importance are fully protected.

Certain economic and cultural conditions might still determine that wildlife farming should be conducted. In such cases, strict guidelines are needed to ensure that the operations succeed as viable farming enterprises, and do not harm wildlife populations.

Wildlife Farming in Rural Areas

In very rare circumstances (e.g., cultural constraints on eating domesticated animals), wildlife farms might be sought in rural areas, with the primary aim of providing protein to rural people. If this is being considered:

- thorough studies should be conducted before establishing a wildlife farm, to ensure that it is indeed the best option available, and that domestic animal farming is not a viable option in the particular situation;
- studies must be conducted to ensure that acquisition of the breeding stock does not pose any threat to a wild population;
- the species farmed must not be endangered, specifically those protected under national legislation, and those on Appendix I of CITES;
- there is no risk of introducing alien, potentially invasive species;
- funds and skilled personnel must be available to ensure major extension services, and long-term support (Jori et al. 1995);
- if any animals are to be sold, strict legal regulations, and the capacity to enforce them, must be in place to prevent the farms being a front for illegal sales of wild-caught animals (see below).

Thorough studies should be conducted before establishing a wildlife farm, to ensure that domestic animal farming is not a viable option.

Wildlife Farming in Urban Areas

High-value, luxury, urban demand for wild meat means that pressure for wildlife farms within easy reach of urban areas is likely to continue. The higher prices paid by some urban consumers will, in some cases, make this economically viable. Under these circumstances, the farms are not a food security solution since urban dwellers who could afford the higher-priced farmed wild meat inevitably have alternative, cheaper, sources of protein, usually fish or domestic meat. Such farms are also not a solution to a conservation problem, since they would not reduce hunting by rural peoples, or supply cheap meat to poorer urban dwellers. The farms might, however, be viable commercial concerns, and be supported politically. If they are indeed established, strict controls must be in place to prevent their posing significant conservation threats to wildlife populations. Specifically:

- the species farmed must not be endangered, specifically those protected under national legislation, and those on Appendix I of CITES;
- there is no risk of introducing alien, potentially invasive species;
- a research study must be done to show that the species can be farmed economically, and that the farmed species (rather than its wild-caught counterpart) will indeed satisfy consumer demand. If neither of these is the case, customers will still demand wild-caught products, and the farm may become a front for illegal trade in wild-caught animals. Such a study should be a legal requirement to obtain a license to establish a wildlife farm;
- the farm can only be established if sales of that species do not break national wildlife trade laws and regulations;
- strict regulations must be in place, and the capacity to enforce them present, to prevent the farms being a front for illegal trade of wild-caught animals. Regulations include the legal necessity to insert transponders into all breeding stock, and sales should only be of the F2 generation or below. Usually, the agency tasked with such regulation is the wildlife

management authority. In almost all tropical countries, their staff capacity, numbers, technical skills and resources are inadequate. Giving them the extra task of regulating farms, if they can do it at all, will inevitably detract from their task of conserving animals in the wild. Policy and law makers should take that into consideration when determining whether such farms should be permitted;

- all local health and hygiene regulations for keeping and slaughtering the animals must be met. The relationships between wildlife and domestic animal health must be considered (see Appendix II for checklist).

Strict regulations must be in place, and the capacity to enforce them present, to prevent the farms being a front for illegal trade of wild-caught animals.

APPENDIX I:

Examples of vertebrate species native to tropical forests proposed or investigated for wild meat production through farming. (From Feer, 1993; Hardouin, 1995; Smythe & Brown de Guanti, 1995; Ntiamoa-Baidu, 1997; Jori et al., 1998; National Research Council, 1999.)

Africa and oceanic islands	Grasscutter or cane rat	*Thryonomys swinderianus*
	Giant rat	*Cricetomys gambianus*
	Ground squirrel	*Xerus erythropus*
	Tailless tenrec	*Tenrec ecaudatus*
	Greater hedgehog tenrec	*Setifer setosus*
	African brush-tailed porcupine	*Atherurus africanus*
	Blue duiker	*Cephalophus monticola*
	Bay duiker	*C. dorsalis*
	Guinea fowl	*Numida meleagris*
	Frogs	unspecified species
Latin America[1]	Agouti	*Dasyprocta* spp.
	Paca	*Agouti paca*
	Collared peccary	*Tayassu tajacu*
	Nutria or coypu	*Myocastor coypus*
	Green iguana	*Iguana iguana*
	Black iguana	*Ctenosaura* spp.
Asia	Bearded pig	*Sus barbatus*
	Sambar deer	*Cervus unicolor*
	Timorese deer	*Cervus timorensis*
	Barking deer	*Muntiacus* spp.
	Chinese soft-shelled turtle	*Pelodiscus sinensis*

[1]The capybara (*Hydrochaeris hydrochaeris*) is often included in literature on wildlife domestication and meat production. However, it occurs in natural grasslands and wetlands of South America (pampas and llanos), and thus falls outside the scope of this paper.

APPENDIX II:

Checklist for evaluating projects to mitigate wildlife health impacts.

The questions below can be used when evaluating wildlife farming projects, during both the funding process and project monitoring and evaluation procedures. Adapted from Wildlife Conservation Society (2003).

1) Does the proposed work comply with relevant local, national, and international laws, regulations, treaties, agreements, and conventions as related to biosafety, animal health, human health, endangered species, trade, phytosanitation, property rights, etc.? Are all legal permits in order (including CITES, national legislation)?

2) Does the proponent describe precautions that will be taken to ensure the protection of human health during this project and address issues related to bio-safety, occupational safety, tourism, and zoonotic diseases (diseases transmissible between animals and people)? Are project staff adequately protected from project–related health risks (e.g.; abattoir workers exposed to potentially infected animal carcasses), and are animals adequately protected from human diseases?

3) Does the proponent describe precautions that will be taken to ensure the protection of wildlife and livestock health during and after the project? Have potential disease transmission risks been adequately addressed in the planning phase of the project? (This question also pertains to any pets or livestock which project staff might wish to have on-site.) What type of risk assessment analysis has been applied?

4) Does the proponent describe appropriate steps for safely moving animals, animal products, and/or animal waste to prevent disease transmission and/or 'downstream' impacts?

5) Has the proponent evaluated the potential environmental impact of any project-related animal or other wastes/run-off, pharmaceutical agents, biologics, drug residues, food additives, or pesticides through toxicity or pathogenicity for non-target species (including soil and water invertebrates and microbes) or through bioaccumulation through the food chain? Has the proponent listed all such materials that will be used within the context of the project?

6) Does the project include the lethal control of disease reservoir or vector species and if so have environmental impacts been minimized and justified? Have non-lethal alternative approaches been considered?

7) Does the proponent have appropriate animal-related experience and training for the techiniques specifically involved in the project? [Note: This requires specific training and experience in husbandry, capture, handling, chemical restraint, care, transportation, and surgery of the relevant animals.]

8) Has the proponent addressed other project scenarios with disease transmission risks between humans, domestic animals, and/or wildlife? Risks can accompany projects that involve, for example, effluent discharge, waste management, construction, water diversion, and contact between species through fences. What type of risk assessment analysis has been applied?

9) If removal of wild animals from populations is occurring, have studies been done to assess the potential adverse effect of removal of that number of animals from the wild population?

10) Where appropriate, does the proposal outline protocols and demonstrate that capabilities are in place for postmortem (necropsy) examination procedures of animals that die due to project-related activities? If an animal's death relates directly or indirectly to project activities, it is important to determine exactly what went wrong in order to avoid repetition of mistakes.

11) Does the proposal demonstrate that protocols/facilities to be used for confining animals meet minimum requirements for humane confinement?

12) Is the introduction of non-endemic species proposed as part of the project? If so, does the applicant:

(a) Justify why the project must use non-endemic species and address the potential risk of the species becoming invasive?

(b) Demonstrate that they have researched the inherent potential of the species for invasiveness (see "IUCN Guidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species" and other references)?

(c) addressed relevant precautionary criteria as published by the IUCN Species Survival Commission Re-Introduction Specialist Group, Invasive Species Specialist Group, Conservation Breeding Specialist Group, and Veterinary Specialist Group?

13) Has the proponent included an evaluation of the potential for animal escape? Risks (beyond the obvious ones to the animal itself) depend on the species and situation, but could include physical danger to humans, animal and human disease risks, as well as danger to ecosystems if the project involves a non-native wildlife species (i.e., a potential alien invasive species: projects involving non-native wildlife species should be discouraged).

14) Does the proponent described plans for emergency response / mitigation if escape occurs?

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