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POLICY PERSPECTIVE

Looking to aquatic species for conservation farming success

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Abstract

Thousands of species worldwide are threatened with extinction due to human activities. For some animals, such as elephants, totoaba, and bluefin tuna, population declines are largely driven by hunting. High prices and large profits create a strong incentive for illegal hunting, even in the face of penalties and strict international restrictions against trade. One innovative solution to help reverse the declines of such species is to farm them to increase supply, thereby reducing prices and decreasing hunting incentives. However, this idea has been criticized as impractical, though some examples exist of successful implementation. Here, we evaluate the hurdles facing endangered species farming as a market-based mechanism to reduce illegal harvest of wild populations and provide guidance on when it is most likely to be effective. Using a simple model, we show how farming costs and enforcement of anti-poaching measures are key drivers of success for this solution. We also argue that many of the most promising candidates are aquatic species that have been largely overlooked. Thus, while conservation farming may not be a solution for all endangered species, it should be more seriously considered for species that could be produced quickly and cost-effectively.

KEYWORDS

aquaculture, conservation farming, endangered species, hunting, species conservation, wildlife trade

1 | INTRODUCTION

Rates of extinction are accelerating globally, and one of the major drivers is direct exploitation of our natural systems and species (IPBES 2019). The global illegal trade in wildlife products is massive and widespread, with a total estimated annual value of $7–23 billion USD (Nellemann et al., 2016). For species that are harvested for luxury products, the risk of being hunted to extinction is particularly high. Lucrative, often illegal markets for extremely rare species can continue to incentivize hunting even at extremely low population levels. As a result, iconic species such as elephants, rhinoceros, and tigers face threats of extinction from continued poaching driven by illicit international trade. Prices can be very high for these highly coveted species (Hall, Milner-Gulland, & Courchamp, 2008); for example, a single high quality totoaba, a critically endangered fish whose swim bladder is in high demand in the Asian medical trade, can fetch tens of thousands of US dollars on the black market (Environmental Investigation Agency, 2016).

Conservation efforts and investment in anti-poaching measures have not succeeded in eliminating the illegal trade in endangered species. The Convention on International Trade in Endangered Species of Wild Fauna (CITES) provides a legal framework for protecting endangered species from trade. Over 180 countries are signatories to CITES, yet trade of

Endangered species continues, much of it on the black market (Challender, Harrop, & MacMillan, 2015). CITES has been criticized for its lack of engagement with the economic realities of the wildlife trade, including community level dynamics, supply side interventions, and the effects of trade bans on demand (Challender et al., 2015).

In the face of this conservation crisis and the failure of traditional regulatory mechanisms to control poaching for many species, an innovative market-based solution has been proposed in both the scientific literature and popular press, reduce prices by farming endangered species (e.g., Damania & Bulte 2007; Tensen, 2016). Recently, proposals to open up legal trade for rhinoceros horns and elephant ivory have renewed debate about the interactions between legal markets, illegal markets, and conservation of hunted species (e.g., Lusseau & Lee 2016). The theory is that a legal market (supplied by farming, ranching, or legal stores of a product such as ivory) increases supply and lowers prices, which should decrease poaching incentives. Although this idea is appealing, conservation farming remains controversial. While there have been successful cases (e.g., alligator; Moyle, 2013) and literature suggesting it may be practical (e.g., Abbott & van Kooten 2011), others suggest that farming can be impractical and even detrimental (e.g., Damania & Bulte 2007; Drury, 2009). A growing legal market can make the problem worse, for instance, by decreasing the stigma associated with the wildlife product or providing opportunities for laundering poached products through legal trade channels (Tensen, 2016).

Much of the scepticism toward endangered species farming comes from studies examining controversial species and those that are challenging to rear, such as tigers and pangolins (Challender et al., 2019; Kirkpatrick & Emerton 2010). In these cases, farming can be expensive—often significantly more expensive than poaching. As a result, economics limit the ability of farming to greatly reduce the market price for these animal products, arguably reducing the conservation benefits of a legal market. However, not all endangered species share these constraining biological characteristics, and regardless, the costs of farming are understudied and often highly speculative. Given the growing list of critically endangered species worldwide, this approach merits a closer look. Here, we examine whether hunting and farming costs can be used to predict the potential upside of conservation-motivated farming. Further, we examine which biological characteristics of endangered species indicate a high potential for conservation farming and specifically whether there are aquatic species that may be well-suited for conservation farming.

2 | THE IMPORTANCE OF COSTS

When farming can produce a product well below the cost of hunting there is much greater potential to relieve hunting pressure (Tensen, 2016). To explore the circumstances in which legal farming of a threatened species could be a market solution for conservation, we draw on a series of conceptual models (see Supporting Information for details). Theoretically, if a new farming operation can produce animal products at a lower cost than the current market price, then farming will expand and the price will fall until the cost of farming equals the market price. If the price falls dramatically, hunting will no longer be profitable and will theoretically cease, allowing the wild population of the exploited species to recover.

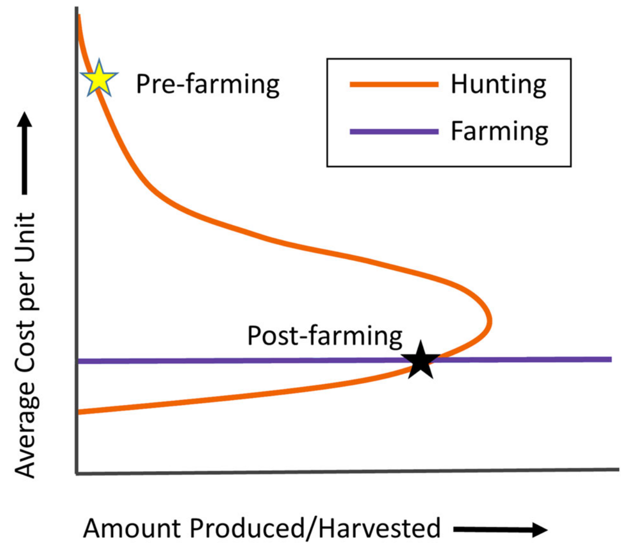

FIGURE 1 A conceptual figure of the average cost per unit of hunting and farming, assuming a constant marginal cost for farming and a backward bending supply curve for hunting due to the increasing scarcity of animals under high hunting pressure. We assume that before conservation farming, the targeted species has a very small population size and thus it is expensive to hunt and very little is being harvested (e.g., the yellow star). Once farming is introduced, hunting will no longer take place if the farmed product can be produced at a lower price. Hunting will only start again if the population increases enough so that the cost of hunting is lower than the cost of farming, which would then reduce the population size; this theoretically results in a post-farming equilibrium (black star)

However, as the wild population recovers, the cost of hunting subsequently declines. For example, less effort may be needed to locate the species, the penalties associated with illegal activity (e.g., fines) may be lowered, or anti-poaching enforcement activities may occur less frequently. If hunting cost declines to such an extent that hunting is once again cheaper per unit than farming, hunting will theoretically resume again. At this point the wild population will theoretically reach a post-farming equilibrium (Figure 1). While this model is useful for discussing policy options, the hunting-farming relationship is more complex than just costs, so these equilibria may not be stable when additional dynamics are considered (e.g., Holden & McDonald-Madden, 2017). This conceptual model also relies on the assumptions that hunters'

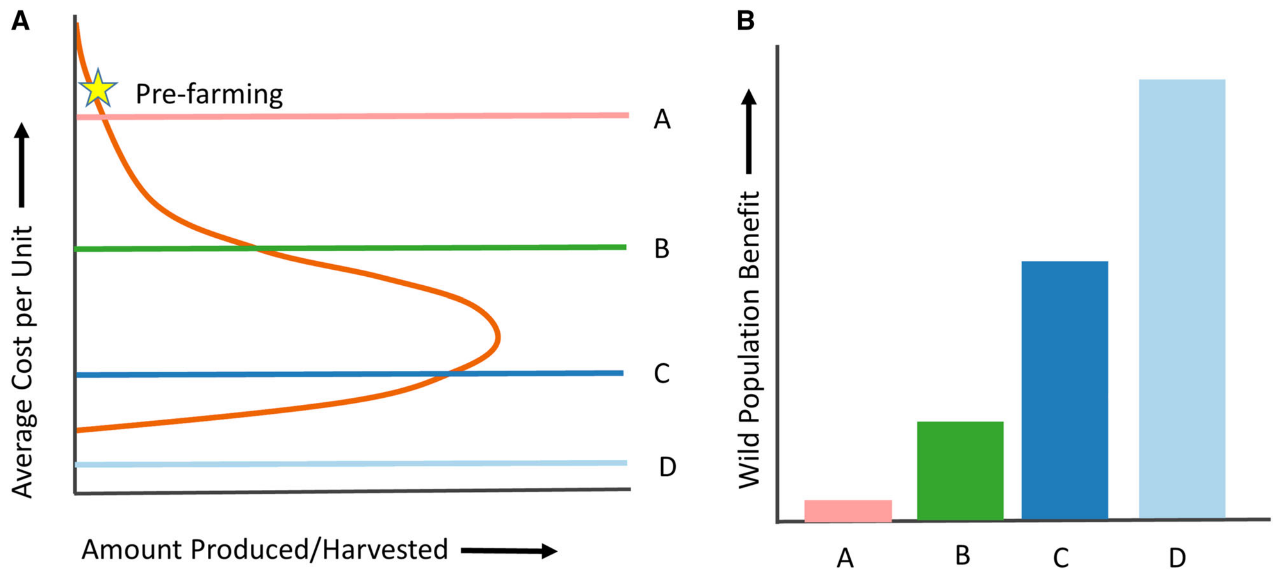

FIGURE 2 A conceptual figure showing the potential benefit of conservation farming based on the relative costs of hunting versus farming. The orange curve represents the cost of hunting and the four parallel lines represent the cost of farming at different average costs. The yellow star represents a possible average cost and level production for hunting before conservation farming is introduced

and farmers' behaviors are economically rational (e.g., they only hunt or farm when it is profitable) and that consumers do not differentiate between wild-sourced and farm-sourced products (see Supporting Information and Figure S1 for further discussion of model assumptions).

Because the relative costs of hunting and farming are so important in determining when hunting would occur, we can use these relative costs to estimate the post-farming population equilibrium for any given species and therefore consider the upside benefit of establishing conservation farming. The larger the difference between the cost of farming and hunting, the greater the potential upside for conservation success through farming of threatened species (Figure 2).

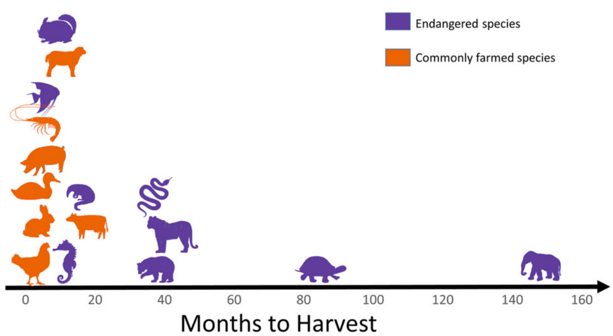

FIGURE 3 Typical time to harvest for commonly farmed non-threatened animals (orange) and for several species for which conservation farming has been suggested or attempted (purple). When the typical time to harvest is not known for a species, time to maturity was used as a proxy

3 | FARMING COSTS: TIME IS MONEY

For many endangered species, especially those for which farming has never been attempted, we do not have a good estimate of the potential costs of farming. However, we can consider which species might be suitable for farming by looking at the types of species characteristics that have the strongest influence on farming costs. Perhaps most important is the growth rate of the species, because costs (due to feed, space, labor, etc.) increase with time in captivity, as does capital depreciation (Harris & Newman 1994). In nature, species have an enormous range of growth strategies. Fast maturation is often associated with high growth rates and fecundity, characteristics that would make a species suitable for cost-effective farming. Indeed, looking across the most commonly farmed terrestrial and aquatic animal species, we found that these species are often harvested from within a few weeks to a few years of birth at most (Table S1). The relatively fast growth and maturation of many commercially farmed animals contrasts with the life history of numerous threatened species for which farming has been suggested (Figure 3). One of the notable examples of successful wildlife farming, the short-tailed chinchilla, has a time to harvest of approximately 9 months (Bieniek, Brach, Maj, Bonczar, & Peczkis, 2011). This is in line with other commercially farmed species, making it unsurprising that the chinchilla is successfully farmed.

While much of the conservation farming literature has focused on land animals, relatively few land animals have been domesticated and commercially farmed, highlighting the challenge of finding terrestrial species that are suitable for farming (Diamond, 2002). In contrast, over 500 aquatic species are already farmed (also known as aquaculture), with a wide diversity of species that are farmed profitably, including numerous species of bivalves, crustaceans, and finfish (FAO 2018). In addition, aquatic species generally have faster and higher success rates of domestication than land animals (Duarte, Marba, & Holmer, 2007) and their production is typically less resource intensive (Tlusty, Tyedmers, Ziegler, Jonell, & Henriksson, 2018), suggesting that aquatic species should be more closely considered for conservation farming.

Intensely exploited aquatic species, such as the totoaba and some seahorses, have already been successfully bred in captivity and are being produced at a small scale. The fast growth rate of the totoaba (Román Rodríguez & Hammann 1997) and relatively rapid maturation of seahorses (FAO 2019) signal that they could be produced at a large scale at competitive prices to help conserve these species, though more in-depth analysis of their farming potential (particularly in terms of the time needed to produce a high quality totoaba bladder) is necessary. Aquaculture potential is also high for a variety of marine species that are threatened by overfishing due to their high value in the aquarium trade (Tlusty, 2002). The Banggai cardinalfish is a notable example of a species that is endangered primarily due to the aquarium trade and has growth and reproductive characteristics that make it suitable for culture. In fact, recent development of large-scale aquaculture for the Banggai cardinalfish in Thailand shows potential for producing farmed fish at competitive prices (Conant, 2015).

4 | HUNTING COSTS: ENFORCEMENT MATTERS

In addition to farming costs, the success of endangered species farming also depends on hunting costs. The overall cost of hunting an animal depends on the ease of capture, the costs per unit effort of hunting, and the population size. Animals that are difficult to find, highly dispersed, or far away from human settlements are likely to require more effort to hunt. In the oceans, species that require more labor or fuel-intensive fishing methods due to depth, distance from shore, or behavior are generally more expensive to fish (Lam, Sumaila, Dyck, Pauly, & Watson, 2011). Species characteristics such as aggregation behavior, habitat preferences, body size, and range contraction also influence the cost of hunting (Burgess et al., 2017).

In the case of illegal hunting, an additional cost is associated with breaking the law, namely the probability of getting caught and the penalty if caught at any stage in the illegal supply chain. Better enforcement anywhere in the supply chain and higher penalties can drive up harvest costs, which increase the conservation benefits of farming.

However, enforcement comes at a cost to the enforcers, which may be hard to sustain, especially if the species is recovering. If the hunting costs per unit effort decline while a species is recovering, the species will eventually have less total recovery than would be predicted from the initial cost differential of hunting versus farming. The dynamics between poaching incentives, enforcement, and wildlife populations can be complex (Holden et al., 2018), yet understanding how and if enforcement can complement wildlife farming is an important component to policy interventions.

5 | WILL FARMING WORK FOR CONSERVATION?

Farming species to promote conservation is not a panacea, but we can predict that success is most likely when farming is much cheaper than hunting (e.g., Tensen, 2016). As mentioned above, farming endangered species for conservation has been far less explored for aquatic species despite their widespread success with domestication. To identify potential candidates for conservation farming, we assessed 147 endangered marine species for which hunting was identified as a threat, using available information about time to maturity and fecundity (see Supporting Information and Table S1). We highlight 10 species from this list of 147 that have relatively high fecundity (defined here as more than 10 offspring per year) and fast maturity (3 years or less to harvest), making them potentially useful species to explore for conservation farming (Table 1 and Table S2). Several of these species, such as the puffer fish and cardinal fish, are currently cultured or being developed for aquaculture. Notably, this list is not exhaustive and uses only a few simple biological traits; there are likely many other threatened aquatic species from our initial list and beyond that could be good farming candidates.

An exercise like this also helps identify species that are unlikely to be good candidates for conservation farming, such as the slow growing Hawksbill turtle that reaches maturity at approximately 30 years of age. Many of the characteristics that make a species expensive to farm (such as slow growth rates and low fecundity) also make it more vulnerable to anthropogenic threats, which make the pool of potential candidates seem constrained. Nonetheless, by looking to aquatic environments, we have shown that there are species that are both threatened with extinction by human exploitation and have the characteristics that could make farming a potentially promising conservation solution.

For species that currently do not have a low enough ratio of farming to hunting costs to achieve conservation benefits from farming, increasing the costs of hunting, such as through additional enforcement or fines may offer benefits. This approach may be more realistic for species that already have a relatively low cost for farming. As an illustrative example using available information, we estimate that the current cost of hunting an adult (100 kg) totoaba would need to be roughly $600

TABLE 1 Select endangered marine species showing life history characteristics that may be conducive to conservation farming. All of the species below are commercially hunted and traded but demonstrate potential for conservation farming due to a time to harvest of 3 years of less and high fecundity (over 10 offspring per year and/or spawning reproductive strategy). While these species show some potential for farming, many other factors, such as the behavior of the species, its diet, its ability to breed in captivity, and the dynamics of the wild population, would need to be investigated before these species could be recommended for conservation farming. See Supporting Information and Table S2 for further details and for references consulted for each species

Species	Common name	IUCN Red List conservation status	Natural range	Use
Anoxypristis cuspidata	Narrow sawfish	Endangered	Western Pacific and Indian Ocean	Food (including for the shark fin trade), medicine, handicrafts
Pterapogon kauderni	Banggai cardinalfish	Endangered	Banggai Archipelago, Indonesia	Aquarium trade
Holothuria scabra	sandfish	Endangered	Tropical Indian Ocean. Western and South Pacific	Food and medicine
Epinephelus akaara	Hong Kong grouper	Endangered	Western Pacific- Japan, China, Korea, Taiwan	Food (live fish trade)
Glaucostegus cemiculus	Blackchin guitarfish	Endangered	Eastern Atlantic Ocean and Mediterranean Sea	Food (shark fin trade)
Thunnus thynnus	Atlantic Bluefin tuna	Endangered	Atlantic Ocean and Mediterranean Sea	Food (Japanese sashimi trade), and game fishing
Takifugu chinensis	Chinese puffer	Critically endangered	Northwest Pacific Ocean	Food (Japanese delicacy)
Chrysoblephus gibbiceps	Red stumpnose seabream	Endangered	Oceans around South Africa	Food
Merluccius senegalensis	Senegalese hake	Endangered	Atlantic coast of North Africa	Food
Pseudotolithus senegalensis	Cassava croaker	Endangered	Eastern Atlantic Ocean from Morocco to Namibia and Cape Verde Islands	Food

to see a population doubling due to farming.[1] In contrast, we estimate that to achieve a doubling of the rhino population, the cost of hunting a kilogram of rhino horn would have to be approximately more than \$120,000.[2] While increasing fines or enforcement can have unintended consequences (see for example Hübschle, 2017; Knapp, 2012), it is worth considering whether strategically coupling increased enforcement with a captive breeding program could help farming for species like the totoaba succeed.

While investment in anti-poaching efforts could drive up the costs of hunting, these investments would need to be ongoing to offer long-term protection. As an alternative, investing in farming, either in short-term research and development or longer term subsidies, could provide similar conservation improvements by driving down the relative costs of farming to hunting. Initial farming costs may be inflated due to the need to certify the farming of an endangered species so that it can be legally traded. Conservation efforts to establish and certify wildlife farms for international trade may make wildlife farming more feasible. In addition, providing assistance to scale-up farming and making production more efficient may provide the jumpstart that is needed for farming to achieve low enough costs to have meaningful conservation benefits.

Some of the commonly raised concerns about the efficacy of wildlife farming, such as the laundering of illegal animal products through legal channels, diminish if farming can be scaled quickly and done inexpensively enough that it outcompetes illegal poaching by driving down the price of laundered product. In addition, if the price of the legal product is much cheaper, laundering illegal product inherently drives down the price that poachers receive.

Another oft-cited concern, that farming can have a negative effect on the wild population, such as through capture of adults or juveniles to replenish or diversify the farming stock (Haitao, Parham, Lau, & Tien-Hsi, 2007), also does not necessarily doom conservation-motivated farming as a solution.

Many farmed species depend on very little to no wild harvest, but even if farming affects the wild population, the key question is whether the net population growth rate is still positive. If so, the post-farming benefits can still be achieved, albeit more slowly. However, any impact on the wild population may make the species more vulnerable to other stressors (such as climate change, habitat destruction, etc.), and therefore may not be acceptable.

The real world offers significant complexities beyond the scope of the arguments and models presented here. We stress that our aim is to elucidate a simple but important point about the relative costs of hunting and farming for evaluating the potential of conservation farming. Additional integrated research on the complexities of human behavior and social drivers, the true costs of farming and hunting, and the dynamics of economic markets and species recovery patterns in relation to conservation success of farming would add important nuance to this discussion (See Supporting Information for additional discussion of potential research extensions). Further, before conservation farming should be supported or expanded for any species, in depth analysis of species and market-specific conditions and their inherent benefits and risks would need to be considered carefully.

A focus on the relative costs of farming different types of animals can help direct conservation farming efforts on the species that show the most promise from a cost standpoint. Unless farming is profitable, it is unlikely to achieve the scale of production that would be necessary to decrease hunting incentives and solve conservation concerns brought on by excessive harvest. Our preliminary look at the issue suggests that aquatic environments may offer some particularly good candidates for conservation farming to succeed.

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ENDNOTES

[1] Based on a cost of 3 Euros/kg for farming red drum (which is a fish in the same family as totoaba) in a semi-industrial farm in Reunion (Mariojouls, Girart, Fischer, & Dao, 2008).

[2] Based on an estimate, albeit possibly out-dated, of the cost of rhino farming (approximately $31,000 per kg) as reported in Crookes and Blingnaut (2015), and that a single hunted rhino would produce 2 kg of horn.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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