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REVIEW | Open Access

A review of commercial captive breeding of parrots as a supply-side intervention to address unsustainable trade

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Article impact statement: Knowledge gaps suggest caution is needed when considering commercial captive breeding of parrots as part of conservation strategies.

Abstract

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The volume and scale of commercial captive breeding of parrots have grown dramatically in recent decades. Although it has been proposed, and is often assumed, that captive breeding can reduce pressure on wild populations, there has been little scrutiny of the scale, viability, or impacts of captive breeding to prevent overexploitation among parrots, compared with similar approaches in other threatened taxa, such as pangolins or tigers. We reviewed the primary and gray literature to quantitatively and qualitatively evaluate evidence concerning 5 criteria, established a priori, for commercial captive breeding of parrots as an effective supply-side intervention. We focused on a sample of 16 threatened parrot species that are heavily traded or for which unsustainable trade has been a factor in the decline of wild populations, representing a range of taxonomic groups, life histories, and native regions. We identified multiple major gaps in knowledge of the extent to which these criteria are met, including a lack of quantitative data on breeding productivity under current commercial breeding practices, the scale and scope of commercial breeding practices in growing parrot markets, particularly in the Middle East and Asia, and the lack of financial viability of captive breeding under effective regulation to prevent laundering or use of wild-sourced specimens as breeding stock. The capacity for captive breeding to displace demand for wild-sourced parrots varied between species, and complex interactions between trade in different species and contexts sometimes made consequences of commercial production difficult to predict. Decision makers and regulatory authorities should approach commercial captive breeding of parrots with caution and take into account knowledge gaps and cross-

> linkages between trade in different species to avoid unanticipated consequences from stimulating and facilitating unsustainable trade in wild-sourced parrots.

INTRODUCTION

Parrots are one of the most abundant taxa in the international pet trade (Bush et al., 2014), with hundreds of thousands of birds involved annually (Chan et al., 2021). The practice of keeping parrots goes back centuries (Boehrer, 2010) and is popular in many cultures due to the birds' colorful plumage, intelligence, mimicry capabilities, and rarity (Jain et al., 2022; Tella & Hiraldo, 2014). This trade has placed enormous pressure on wild populations of parrots (Berkunsky et al., 2017; Nandika et al., 2021), which are among the most threatened of all avian taxa (Olah et al., 2016). Overexploitation to supply the exotic pet trade has driven the extinction in the wild of species, such as Spix's macaw (*Cyanopsitta spixii*), and caused drastic population declines in formerly widespread and abundant species, such as the gray parrot (*Psittacus erithacus*) (Annorbah, 2016; Hart et al., 2016). This trade has also led to the spread of infectious diseases (Fogell et al., 2018), and the introduction of exotic and/or invasive species (Westphal et al., 2008). In addition traded animals may suffer poor animal welfare during capture, transport, and arrival at end destinations (e.g., Hart et al., 2013), as many parrots have high caretaking demands that are challenging to meet (Bradshaw & Engebretson, 2013).

Commercial captive breeding, sometimes called *wildlife farming*, is defined as the breeding of specimens in a controlled environment for economic benefit (CITES, 2010a, 2010b). It is often proposed as a supply-side intervention to help prevent overexploitation of species by increasing supply from a sustainable source and thus reducing pressure on wild populations (Alves et al., 2012 Collar & Butchart, 2014; Wang et al., 2019). In the case of gray parrots, it has been argued that greater regulation of trade in captive-bred parrots (such as requirements to register breeding operations and demonstrate legal acquisition of breeding stock) reduces their supply and creates an opportunity for illegal trade in wild parrots (CITES, 2019b). However, increasing the supply of captive-bred wildlife may also increase demand for wild-sourced animals by stimulating latent demand and normalizing consumption, which is not met by production of captive-bred specimens (Rizzolo, 2021); increasing demand for wild-sourced specimens as breeding stock; and creating opportunities for the laundering and misdeclaration of wild-sourced specimens as captive bred, which are challenging for law enforcement agencies to detect (Tensen, 2016) (Figure 1). There have been several attempts to determine the conditions under which commercial captive breeding may be effective at reducing demand for wild-sourced specimens (Biggs et al., 2013; Phelps et al., 2014; Tensen, 2016). These reviews highlight how markets can react unpredictably to interventions and that multiple conditions need to be met for breeding to successfully substitute wild resources, such as cost-effectiveness and the presence of adequate measures to counter laundering. These conditions

have been found not to be met in a number of reviewed cases, suggesting that commercial captive breeding as a conservation approach should be treated with caution (Biggs et al., 2014; Phelps et al., 2014; Tensen, 2016).

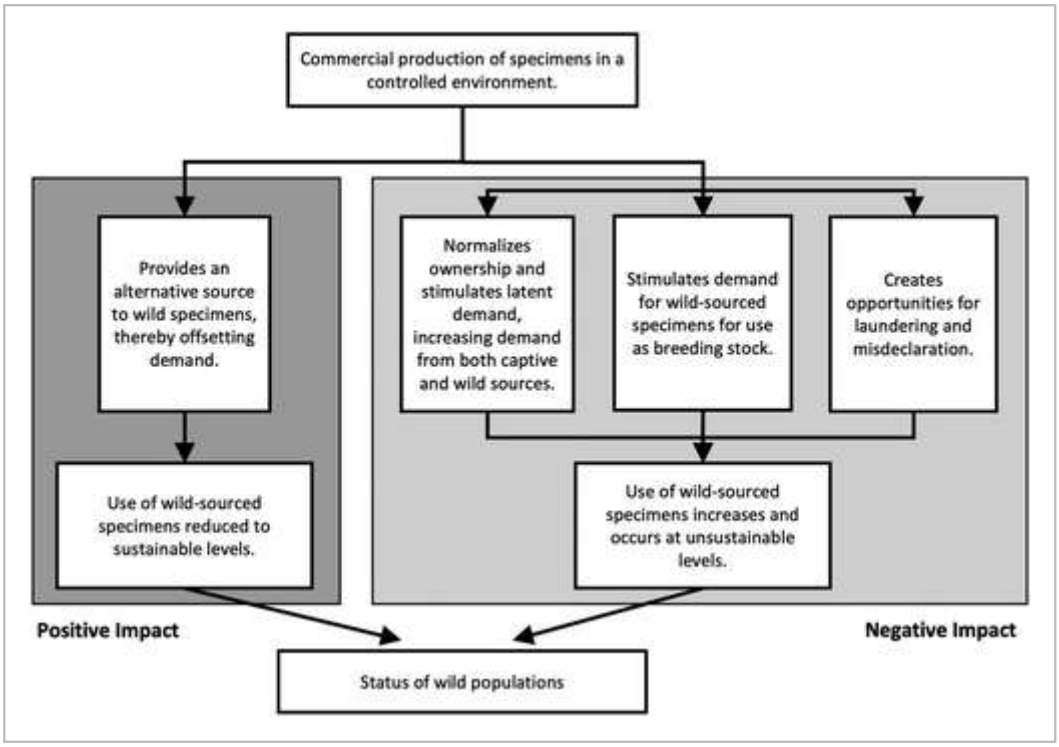

FIGURE 1

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Pathways by which commercial captive breeding of wildlife may positively and negatively affect the status of wild populations.

Captive breeding of parrots to supply exotic pet markets has been of growing relevance in many countries. Prior to 1990, the majority of parrots in international trade were sourced from the wild (Chan et al., 2021). However, the scale of international trade in captive-bred parrots has grown substantially, increasing from approximately 60,000 reported in the year 1990 to over 500,000 in 2020 (CITES trade statistics derived from the CITES Trade Database, UNEP World Conservation Monitoring Centre, Cambridge, UK). As a result, captive-bred parrots now dominate international trade (Chan et al., 2021). International trade in parrots has largely been dominated by South Africa (Chan et al., 2021), where mega-facilities oriented for export markets have been established. The increase in captive production could be driven by multiple factors, including investment in infrastructure, improvements in technology and avicultural techniques, shifting consumer preferences, increasing affluence, and a generally permissive regulatory environment.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is the primary multilateral treaty that regulates wildlife trade between its 183 member parties. Species are listed on 3 appendices (I, II, and III) that determine how international trade in those species is regulated between countries and, depending on national-level legislation, often also within them. Captive breeding is considered by CITES as having advantages over wild harvesting (CITES, 2019a) and as having the potential to support conservation by reducing harvest pressure. Although there is no single framework to regulate trade in captive-produced specimens, CITES Article VII paragraphs 4 and 5 make provisions for trade in captive-bred wildlife alongside a number of additional resolutions and decisions (CITES, 2022a). Animals traded as captive bred (source code = C) must be conceived in a controlled environment to legally acquired breeding stock (wild or captive) that can be maintained without requiring new specimens from the wild and that are capable of reliably producing second generation (F2) offspring (CITES, 2010b). Species on Appendix I, in which international trade of wild-sourced specimens for commercial purposes is generally prohibited, may be traded for commercial purposes if they are captive bred and sourced from a facility registered with CITES (source code = D). To be registered, a facility must meet multiple criteria including using an appropriate and secure marking system and satisfying national CITES Management Authorities that it is making a continuing meaningful contribution toward the species' conservation (CITES, 2010c). However, some leniency in meeting these requirements has been advocated for by avicultural interest groups and adopted by CITES Parties (CITES, 2019b). The number of operations registered to trade Appendix I parrot species has risen from 5 in 2016 to 212 in 2022 (spread across 7 countries for 9 species), an increase of over 4000% in 5 years (CITES, 2022b). The direction of travel toward a more permissive regulatory environment is also evident at the national level with major economies, including China, currently revising national legislation to make it potentially easier to own, commercially breed, or sell CITES-listed parrots.

As levels of production and volumes of international and domestic trade in captive-bred parrots increase, there is a growing need for a robust evidence base to ensure policy decisions designed to achieve positive conservation outcomes do not have unintended consequences. The widespread misdeclaration of species, misuse of source codes, and laundering of wild-sourced animals through captive-breeding facilities has raised concerns that the benefits of captive breeding may be reduced or undermined (CITES, 2019a; TRAFFIC, 2016). Yet, despite these concerns, the role of captive breeding as a supply-side intervention to prevent the overexploitation of wild populations has received little scrutiny by researchers. A recent review of interventions to address illegal parrot trade stated that there had been no in-depth, quantitative assessment of the capacity, extent, and role of commercial captive breeding in parrot trade (Sánchez-Mercado et al., 2021). In contrast, wildlife farming as a supply-side intervention has been the subject of extensive research and debate in a number of other taxa,

such as tigers (Abbott & von Kooten, 2011), bears (Crudge et al., 2020), and turtles (Haitao et al., 2008).

We reviewed the peer-reviewed and gray literature to evaluate the evidence concerning the potential for commercial production of parrots in captivity to be an effective supply-side intervention for preventing the overexploitation of wild populations. Specifically, we aimed to quantitatively and qualitatively evaluate information concerning 5 criteria (Table 1), identify key knowledge gaps, and consider the implications of what is and is not known for the development of evidence-based policies and conservation strategies. Given the broad diversity of species and countries in which captive breeding interacts with trade in wild parrots, we focused on 16 threatened parrot species, traded in significant numbers internationally and for which international trade has been a major factor in the decline of wild populations.

TABLE 1. Criteria used to evaluate the effectiveness of captive breeding as a supply-side conservation strategy (adapted from Tensen [2016]) and the type of information that could act as evidence for evaluating each criterion.

Criterion	Description of relevant information
Preference Legally produced captive-bred animals provide an acceptable substitute to wild.	Consumer preference for either wild-sourced or captive-bred parrots (excluding price as a reason) Consumer preference for species rarity
Supply Captive production can adequately meet existing and either not stimulate or be able meet latent demand.	Relative volumes of captive-bred and wild-sourced parrots in international trade Breeding productivity rates in captivity Experience of ease or difficulty in captive breeding Range in price over time as an indicator of change in supply and demand associated with captive breeding Changes in demand in response to changes in parrot availability and supply (latent demand)
Cost Legally produced captive-bred animals will be more cost-efficient than those sourced from the	Relative price of captive bred and wild sourced to consumers (any point in commodity chain, e.g., breeders, shop owners, pet owners)

Criterion	Description of relevant information

METHOD

Review framework

We adapted an existing set of criteria used by Tensen (2016) for evaluating the suitability of captive breeding as a conservation tool (Table 1). Other frameworks have been proposed that place a greater emphasis on market dynamics and factors affecting cost-effectiveness (Phelps et al., 2014), but we chose to use the framework set out by Tensen (2016) because it covers a broader range of issues relevant to the trade in parrots including the potential to stimulate demand and of using wild-sourced animals and breeding stock.

For each criterion, using the detailed explanations provided in Tensen (2016) as guidance, we identified types of information that could act as evidence of whether a criterion was fulfilled or violated (Table 1). We adjusted the framework to move information about reproductive productivity from criterion 3 (cost-effectiveness) to criterion 2 (ability to meet demand) because we considered it more relevant for assessing the capacity of breeding to meet demand for a given species than cost-efficiency, although it has an important bearing on both. In Tensen's (2016) review, these criteria are presented as conditions that must not be violated for captive breeding to be considered a conservation tool. We considered evidence of violations as clear red flags for areas of risk that demand robust assessments to demonstrate that the scale and scope of violations do not contribute to greater pressure on wild populations. For each criterion, we quantitatively and qualitatively synthesized the evidence.

Species selection

Given the vast diversity in parrots involved in trade, we limited our review to a sample of parrot species that are threatened with extinction, that are present in recent international trade, and that have been or continue to be threatened by trade. We began by establishing species that are threatened and have been traded internationally in high volumes. We downloaded comparative tabulation reports from the CITES Trade Database (**http://www.unep-wcmc-apps.org/citestrade/trade.cfm**) for all trade reports of live parrots for commercial purposes (trade term code *LIV* and purpose code *T*) from 2010 to 2020. These reports detail the volume of CITES-listed birds imported, exported, and re-exported and are mandatory for parties to record and report under CITES. Where there was a discrepancy between importer and exporter values, the highest value was taken. Data were cleaned by removing duplicate rows and records where the unit was specified as something other than number of specimens (n = 11). We then filtered for species that were listed as threatened on the International Union for

Conservation of Nature (IUCN) Red List (categories vulnerable, endangered, and critically endangered). These species were ranked by the total volume of trade, and the top 10 species were selected. We then reviewed the Birdlife Datazone text account (http://datazone.birdlife.org/home; accessed 16 March 2022) for the top 10 species to identify whether international trade was listed as a serious historic, ongoing, or future threat. Two species, the swift parrot (*Lathamus discolor*) and Malherbe's parakeet (*Cyanoramphus malherbi*), were removed from the list because trade was not mentioned as a pressing threat or concern and were replaced by species ranking 11 and 12, the yellow-naped amazon (*Amazona auropalliata*) and cape parrot (*Poicephalus robustus*).

To incorporate previous assessments of parrots of conservation concern due to trade and calls for CITES action, we referenced the rapid assessment of Appendix I taxa that could potentially benefit from further CITES action (AC31 Inf. 6/PC25 Inf. 8). This rapid assessment assessed species based on extinction risk, biological vulnerability, threat from trade, and management effort to identify a shortlist of species that may warrant greater attention and action. An additional 6 species identified on this shortlist but not already included in our list were added to create a list of 16 focal species: gray parrot, sun parakeet (*Aratinga solstitialis*), black-cheeked lovebird (*Agapornis nigrigenis*), white cockatoo (*Cacatua alba*), white-bellied parrot (*Pionites leucogaster*), crimson-bellied parakeet (*Pyrrhura perlata*), chattering lory (*Lorius garrulus*), yellow-headed amazon (*Amazona oratrix*), yellow-naped amazon, cape parrot, red-and-blue lory (*Eos histrio*), salmon-crested cockatoo (*Cacatua moluccensis*), yellow-crested cockatoo (*Cacatua sulphurea*), military macaw (*Ara militaris*), hyacinth macaw (*Anodorhynchus hyacinthinus*), and lilac-crowned amazon (*Amazona finschi*). This list included taxa from Africa, South America, and Southeast Asia, including species with different sizes, colors, temperaments, and life histories. We may not have captured literature focused on other parrot species (e.g., Australian species) that may have relevant general implications (e.g., Vall-llosera & Cassey, 2017), and because we used CITES data to select our sample, we may have overlooked species heavily threatened by domestic trade, such as the orange-fronted parakeet (*Eupsittula canicularis*) (Cantú-Guzmán et al., 2007). However, we believe that the diversity of species and literature captured in our review is representative of the variety of issues involved in commercial captive breeding and that our findings are relevant for evaluating captive breeding in a broader range of species and contexts. The data used to evaluate the criteria along with a full citation list and coding of literature are provided in the Supporting Information.

Literature search and data extraction

We began the literature review with a search of major literature databases with several key terms. We searched Google Scholar, Web of Science, and Science Direct for the phrases "*captive breeding* + *parrot*," "*captive bred* + *parrot*," and "*commercial breeding* + *parrot*," allowing for both peer-reviewed and gray literature. We also searched for relevant reports published by TRAFFIC

and WWF with the term *parrot*. In addition, we conducted species specific searches with the focal species English and scientific names in combination with *captive breeding* and *aviculture* (e.g., "*Ara militaris* + *aviculture*" or "*sun conure* + *captive breeding*"). We included both peer-reviewed published literature and nongovernmental organization (NGO) and convention reports, book chapters, magazine articles, and CITES Non-Detriment Findings. The type of source was recorded.

During this search, we filtered results based on the relevance of the title and abstract and by doing a rapid specific text search for *captive* and *captivity*. Our aim was to identify literature that discussed commercial breeding, here defined as breeding to sell, which may range from hobbyists to large-scale farms, that was either generally or specifically relevant to our sample of parrot species. Therefore, we excluded sources that described or discussed ex situ captive breeding for the conservation purposes of reintroduction or maintaining a captive population that did not mention supplying the pet trade; discussed parrot breeding husbandry, including nutrition, disease, and genetics, without reference to reproductive productivity or breeding to supply trade; and specifically discussed parrot species outside our focus sample, for example, only addressing Australian parrots. Excluded literature, along with literature on the presence and severity of ongoing trapping and drivers of legal and illegal trade in parrots, may contain additional information that is of value for understanding the positive and negative impacts of captive breeding and trade policy more broadly.

Once we established our initial sample, we carefully reviewed sources and identified evidence related to the 5 framework criteria (Table 1). Papers would sometimes cite other literature or provide alternative examples. If this literature was relevant and had not appeared in our initial search, we added this literature to our literature sample. We recorded whether this information was general to parrots or a broader parrot group (e.g., cockatoos) (referred to as *general*) or specific to a focal species (categorized by species). We recorded whether the evidence was anecdotal observation and expert knowledge or opinion (referred to as *primary anecdotal*), the results of analyses of original data (referred to as *primary data*), or conclusions based on the analysis of other peer-reviewed literature (referred to as *secondary*). In summarizing and reviewing available literature, our framing question was, "Is there recent, reliable information to evaluate this criterion across a range of threatened parrot species?"

RESULTS

We identified 51 sources published from 1988 to 2022 (Figure 2), including 15 peer review journal articles, 15 reports (including action plans and workshop documents), 14 magazine articles, 2 unpublished thesis dissertations, 2 CITES documents, and 4 book chapters from 2 books. Evidence was identified for all criteria, but less information was available regarding cost-effectiveness (criterion 3, $n = 9$) and the necessity of restocking from the wild (criterion 4, $n = 4$)

(Figure 3). The most common type of evidence was primary anecdotal (n = 33), followed by primary data (n = 22) and secondary (n = 5). Recent literature contained mostly analyses of data (75%) (Figure 4) and primarily contained information relevant to evaluating the degree to which captive breeding can supply demand (criterion 2) and the presence of laundering (criterion 5) (Figure 5). In contrast, literature published prior to 2012 contained information relevant to all criteria, but the majority of this information was anecdotal (88.8%).

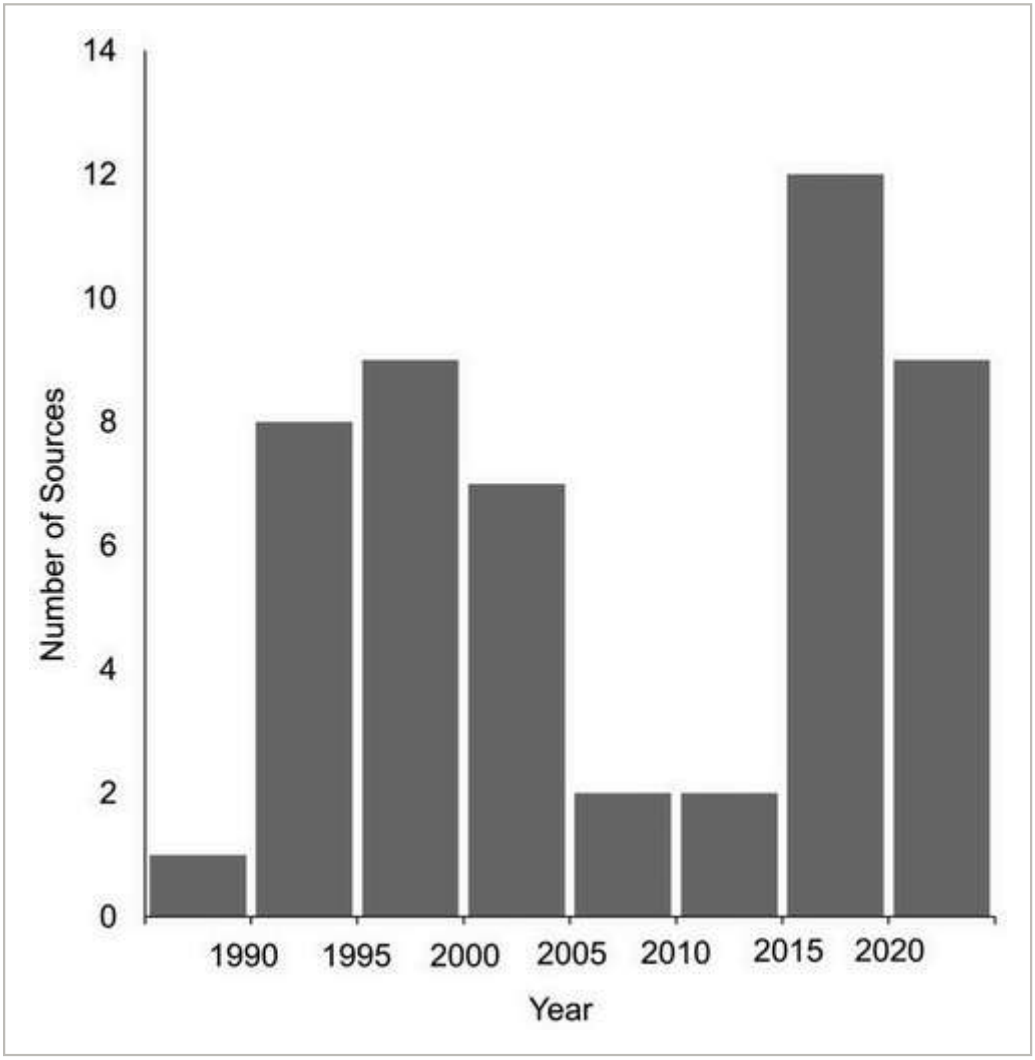

FIGURE 2

Year of publication of sources that included information relevant to evaluation of criteria for assessing commercial captive breeding of parrots for conservation purposes from 1988 to 2022.

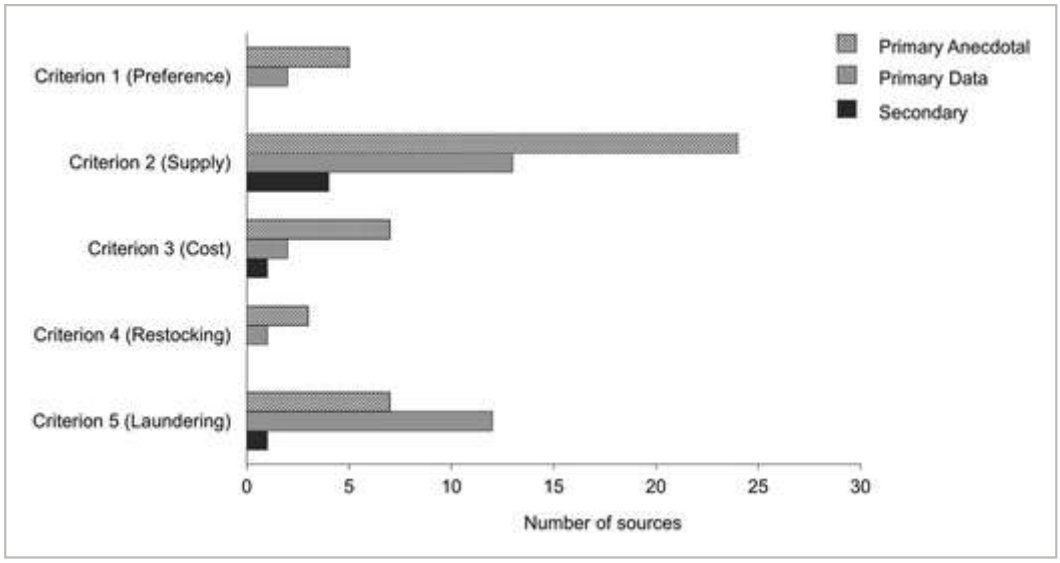

FIGURE 3

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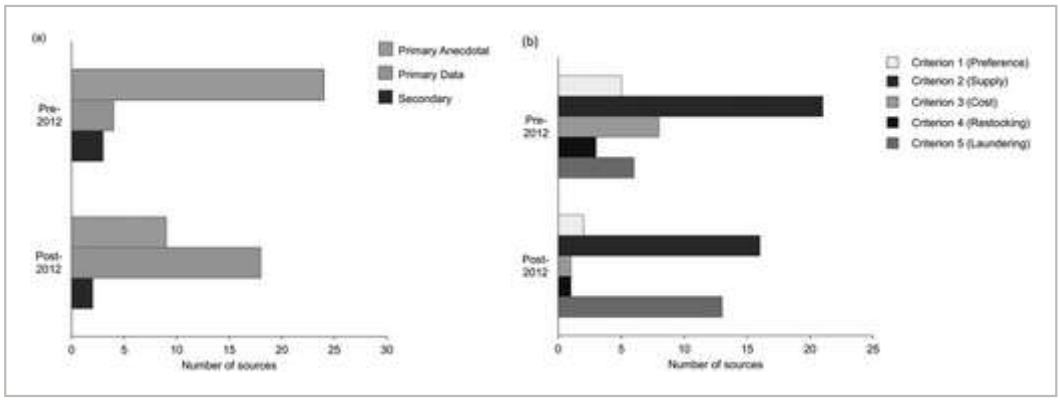
Number of sources containing primary anecdotal (anecdotal observation and expert knowledge or opinion), primary data(results of analyses of original data), secondary, (conclusions based on analyses of other literature) relevant for evaluating each criterion for assessing commercial captive breeding of parrots (desribed in Table 1). References that include information on multiple criteria and for multiple species are included as multiple independent sources.



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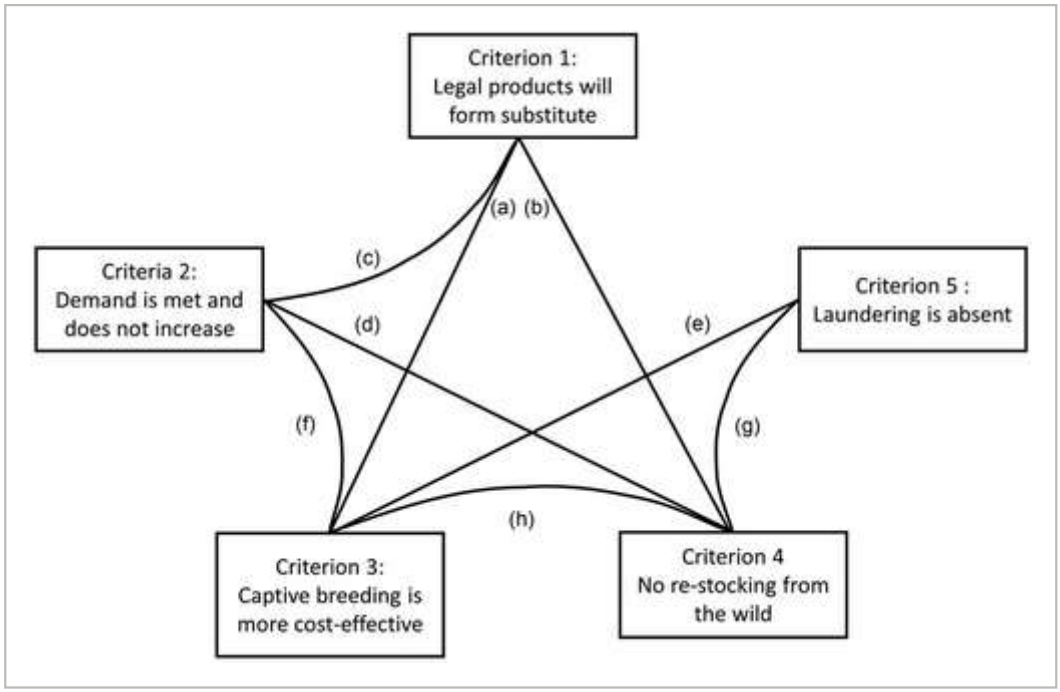
Number of sources (a) containing primary anecdotal (anecdotal observation and expert knowledge or opinion), primary data (results of analyses of original data), and secondary evidence (conclusions based on the analysis of other literature) and (b) containing evidence relevant for evaluating each criterion for assessing commercial captive breeding of parrots (described in Table 1), divided based on recency of publishing (before or after 2012).



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Interaction and trade-offs between criteria within the Tensen (2016) evaluation framework: willingness to pay more for captive-bred parrots (Jain et al., 2021) may reduce the necessity to match the lower price of wild-sourced birds (a); breeders may restock from the wild because of a preference for characteristics linked to wild birds, such as breeding probability in the first year (Clubb et al., 1992) (b); rising trade may lead to greater demand for other rarer or more desirable species because of "upgrading" (Jain et al., 2021) (c); if lack of new genetic material leads to inbreeding depression, captive breeding may become less productive (Jordan, 1995) (d); monitoring and regulations to prevent laundering may make captive breeding less cost-efficient (Ortiz-von Halle et al., 2018) (e); reliable data on captive-breeding productivity can help identify cases of probable laundering; if commercial breeders prefer small fast-breeding species (Clubb, 1993), there may be a lower supply of larger species for which there is rising demand (f); stocking and restocking from the wild may provide cover for laundering wild birds directly through captive facilities (g); and captive-bred breeding stock is more costly to buy and maintain than buying wild-sourced stock (Clubb, 1993) (h).

Specific data were found for all 16 species, although the amount of information varied between species. The species for which the most sources were found were gray parrots, which were specifically mentioned in 11 sources (22%), followed by the yellow-crested cockatoo (n = 7, 13.7% of sources) and salmon-crested cockatoo (*C. moluccensis*) (n = 6, 11.7% of sources).

Consumer preference (criterion 1)

For captive-bred parrots to provide an effective alternative, they must be perceived as a viable substitute, with price being equal. Beliefs about preferable traits in wild-sourced specimens and demand for rare species that are not easily supplied by captive production have proven a challenge to substitution in other wildlife (Tensen, 2016). We identified 7 sources that contained information relating to consumer preference based on source or rarity.

Recent peer-reviewed research indicated that there is very little consumer preference for wild-sourced parrots besides price and even a preference for captive-bred birds. This included a survey of 105 bird conservation experts from 53 countries (Ribeiro et al., 2019) and a survey of parrot owners in Singapore (Jain et al., 2022) and was reflected in expert observation of US aviculture in the 1990s (James, 1992). Anecdotal reasons provided for preferring captive-bred birds include more docile birds (Collar, 2000) and better breeders, in the case of salmon-crested cockatoos (Allen & Johnson, 1991). However, early expert opinion indicated a preference among breeders for wild-sourced birds because they may breed sooner than captive-bred birds, which may take years to sexually mature (Clubb, 1992; Clubb et al., 1992). There is an absence of recent data to indicate whether these preferences hold in other growing parrot markets beyond Singapore, with information on current breeder preferences particularly lacking.

Rarity has been identified as an important factor influencing choice and demand in recent peer-reviewed research, both in global bird trade (Ribeiro et al., 2019) and according to parrot owners (Jain et al., 2022). However, the prevalence and strength of demand for rarity in many markets remain unclear, such as whether demand for rarity is widespread among parrot owners from different cultural and socioeconomic backgrounds (Jain et al., 2022) or mainly restricted to a smaller group of collectors and breeders (Allen & Johnson, 1991).

Supply (criterion 2)

For captive breeding to displace wild products in the market, production must be sufficient to supply a substantial proportion of demand without stimulating latent demand to an extent that captive production cannot meet it (Tensen, 2016). We identified 37 sources that contained information relating to the capacity of captive breeding to supply demand.

Recent peer-reviewed articles and NGO reports indicated a substantial proportion, and in some cases the majority, of parrot trade involves parrots produced in captivity in a number of markets and species. These include analyses of trends in CITES trade data across parrots globally (Chan et al., 2021) focused on specific countries (Aloysius et al., 2020; Wang et al., 2021) and on specific species (Martin, 2018; Poole & Shepherd, 2017) (range = 25–68.3%); online and physical market surveys and social media (Davies et al., 2022; Martin et al., 2018; Sy et al., 2022); and owner surveys (Jain et al., 2022). Expert observations of parrot markets in the United

States and the European Union following bans on the import of wild birds (Clubb, 1992; James, 1992) and the reported decline in exports of wild South American parrots due to sufficient international captive supply (Ortiz-von Halle et al., 2018) also suggested that captive breeding may displace wild sourcing in some cases. However, this research may have overestimated the proportion of captive bred birds in trade because CITES data do not capture the relative volume of illegal wild-sourced trade and may include misdeclaration (Martin, 2018; Poole & Shepherd, 2017), and owners may not answer honestly or know the true source of their bird (Jain et al., 2022). Some markets remain almost entirely supplied by wild parrots (Atoussi et al., 2020).

The relative proportion of different sources in trade may be affected by multiple factors including trade restrictions and the relative cost and ease of accessing wild birds. This makes it difficult to gauge true levels of demand and if they are adequately met by captive breeding. Trends in market prices can provide another indicator of the state of demand and supply. Economic modeling of aviculture markets predicts that because parrots are long-lived and durable, captive breeding will eventually lead to market saturation in all species, leading to low market prices (Robinson, 2001). These predictions may not hold in all cases, as the model does not account for limited productivity in certain species or that parrots may not be long-lived under poor welfare and biosecurity conditions. There have been observations of falling prices in US aviculture (Clubb, 1992) and price changes in crimson-bellied parakeets (*P. perlata*) (Ortiz von-Halle et al., 2018) and cape parrots (CITES, 2002; Snyder et al., 2000). However, we found no systematic research analyzing trends in parrot prices in different countries and species that could be used to test model predictions.

Species vary in their life history, diet, and ecological and behavioral requirements, which affect their captive reproductive capacity and thus the potential for captive breeding to supply demand. Regarding our focus species, numerous anecdotal sources from knowledgeable figures in aviculture suggest that small, fast-breeding species can be bred in sufficient quantity to supply and exceed market demand, including sun parakeets (*A. solstitialis*) (Clubb, 1992; Voight & Voight, 1998), black-cheeked lovebirds (*A. nigrigenis*) (Dodman et al., 2000; Snyder et al., 2000), and crimson-bellied parakeets (Jordan, 1995, 1998; Ortiz von-Halle et al., 2018). This is further supported by primary research on source in sun parakeets (Allen & Johnson, 1991; Wang et al., 2021) and assessment of early breeding records and expert opinion in black-cheeked lovebirds (Warburton, 2003). In contrast, anecdotal reports and expert opinion broadly suggest that macaws (Allen & Johnson, 1991; Clubb, 1992; Clubb & Clubb, 1991; Derrikson & Snyder, 1992), amazons (Clubb, 1992; Derrikson & Snyder, 1992; Thompson, 1995), cockatoos (Allen & Johnson, 1991; Budiani & Raharningrum, 2018; Furnell & Jain, 2019; Jordan, 2013; Vriends, 1997), and cape parrots (CITES, 2002; Snyder et al., 2000) are challenging to breed with concerns that breeding capacity may be unable to supply demand, although exceptions include

the white cockatoo (*C. alba*) (Marelli et al., 2020; Shepherd et al., 2012; Vriends, 1997) and military macaw (*A. militaris*) (Clubb & Clubb, 1991). However, much of these data are outdated, anecdotal, discrepant regarding single species, such as the white-bellied parrot (Clubb, 1992; Gonzales, 1996; Smith, 1991) and gray parrot (Allen & Johnson, 1991; Dennison, 2004), or not species specific. We found no recent quantitative research on realistic reproductive capacity in commercial settings. Quantitative assessments were either outdated (Cantú-Guzmán et al., 2007; Dennison, 2004; Mulliken, 1995) or had a very small sample size (Marelli et al., 2020).

Expert opinion and owner interviews suggested that increased visibility and availability of parrots from captive breeding, including through sharing on social media, may be increasing overall demand in several ways. Upgrading is a phenomenon where owners initially purchase common, fast-breeding species before proceeding to seek out larger, rarer, and more challenging species, such as macaws and cockatoos, and has been observed in US aviculture (Clubb, 1992) and parrot ownership in Singapore (Aloysius et al., 2020; Jain et al., 2022). Parrot owners also report encouraging others to join in the hobby ("poisoning") (Aloysius et al., 2020; Jain et al., 2022), and the visibility of parrots and hobbyist groups on the internet and social media has also been proposed as contributors to rising demand (Jain et al., 2022; Wang et al., 2021). Finally, it has been suggested that the visibility of expensive captive-bred birds stimulates potential consumers to buy affordable wild parrots instead (Cantú Guzmán et al., 2007), but there is currently no survey data to support this.

Cost (criterion 3)

For captive breeding to be an effective supply-side intervention, it must be cost-effective, meaning that captive-sourced parrots are competitive in terms of price and that the venture is financially viable for breeders (Tensen, 2016). We identified only 9 sources that provided information on the cost-effectiveness of breeding.

Early anecdotal and expert observations indicated that captive breeding has struggled to be profitable (Cravens, 1993), particularly in larger species, such as macaws and amazons (Clubb, 1992; Derrikson & Snyder, 1992). Economic modeling also predicts that many breeders will struggle to be profitable if markets become saturated and prices fall (Robinson, 2001). A recent detailed report on the bird trade in South America showed that in Brazil, captive breeders argue that they struggled to be profitable because of strict monitoring and regulation in place to prevent laundering, such as strict restriction on the number of closed rings provided to breeders (Ortiz-von Halle et al., 2018). However, there has been no quantitative research into the cost-effectiveness and profitability of breeding in the last decade to evaluate the economic viability of breeding different species under current breeding practices in different countries and accounting for the cost of measures to prevent laundering and illegal trade. We found only one detailed assessment of profitability regarding gray parrots, but this was based on wild-

sourced breeding stock, did not account for the impact that regulations, such as involvement in studbooks or genetic testing, may have on profitability, and is now outdated (Dennison, 2004).

Several assessments across a range of species across different continents indicated that captive-bred birds are broadly more expensive than wild-sourced parrots, in part because of major up-front costs associated with investment in infrastructure (Cantú Guzmán et al., 2007; Mulliken, 1995; Ortiz-von Halle et al., 2018)—in some cases up to 9 times more expensive (Cantú Guzmán et al., 2007). We could find no recent systematic quantitative research on the relative price between captive-bred and wild-sourced parrots in different countries.

Restocking (criterion 4)

For captive breeding to reduce pressure on wild populations, it should not rely on wild-sourced animals to supplement or supply breeding stock (Tensen, 2016). This principle is upheld by CITES conditions for using source code C (bred in captivity) (CITES, 2010b). Historically, countries that developed captive-breeding industries have heavily relied on wild-sourced stock (Allen & Johnson, 1991; Chan et al., 2021; Martin, 2018).

We found one source that documented that South Africa historically imported large volumes of wild-sourced gray parrots as breeding stock for its rapidly developing captive-breeding industry (Martin, 2018), but no recent evidence on the continued necessity and importance of wild stock to maintain captive-breeding operations. Concerns were raised in 3 avicultural articles regarding the risk and impact of small gene pools and inbreeding if captive populations are not supplemented with new wild-sourced genetic stock (Cravens, 1993; Jordan, 1995; Low et al., 1997). However, we could find no recent sources that explicitly measured and evaluated genetic diversity and the impact on health and productivity in commercial breeding operations, addressed how this can be mitigated through management of existing breeding stock, or explored the extent to which this is a concern among breeders of threatened parrot species.

Laundering (criterion 5)

Laundering and misdeclaration pose a major threat to wild populations and the prospect of sustainable supply, as they provide a legitimate cover for illegal trade that can be difficult to detect and regulate (Tensen, 2016). We found 19 sources that included evidence of laundering, misuse of trade codes, and challenges in distinguishing between wild and captive parrots, of which 13 were published in the last decade.

We found widespread recent evidence of possible laundering through the misuse of CITES source codes and through captive breeding facilities across species, evidenced by the misdeclaration of imports and exports of so-called captive bred birds from countries without the requisite breeding facilities (Furnell & Jain, 2019; Martin, 2018; Shepherd et al., 2012; Sy

et al., 2022; VKM, 2020); suddenly or unexpectedly high numbers of birds declared as captive bred (Martin, 2018; Mulliken, 1995; Prijono, 2008); and seizures where traders were unable to provide proof of source or provided false documents (Pires et al., 2021; TRAFFIC, 2017). Although several papers described or expressed concern about laundering of wild birds directly through commercial captive-breeding facilities (Canlas et al., 2017; Snyder et al., 2000), we did not find any systematic assessments of the extent of this practice.

The difficulty in distinguishing between wild-sourced and captive-bred parrots by authorities and in markets has also been well documented. In 2 sources, anecdotal reports indicated that law enforcement finds it more difficult to enforce a partial ban with legal avenues compared to a full ban, due to the opportunity for loopholes and misdeclaration (James, 1992; Ortiz-von Halle et al., 2018). This is supported by seizure data in Mexico, where illegal trade in authorized species was higher than prohibited species (Cantú-Guzmán et al., 2007). Although techniques for identifying captive-bred birds have been implemented and recommended, including closed leg rings (Chng & Eaton, 2016; Martin et al., 2018; Ortiz-von Halle et al., 2018) and documentation (Budiani & Raharningrum, 2018), these are not practiced universally. In Singapore, researchers were unable to obtain any data necessary for determining legality (Eaton et al., 2017), leg rings were rare (Eaton et al., 2017), and most owners had no paperwork from purchasing their parrots (Jain et al., 2022). There is also evidence of closed rings being placed on chicks taken from the wild or hatched from wild eggs in smuggling and laundering operations (TRAFFIC, 2017; Warburton, 2003).

DISCUSSION

Parrots have been bred to be traded for pets for at least hundreds of years, and this practice is a popular pastime in cultures around the world (Boehrer, 2010). However, in recent decades, the scale and scope of this practice have increased dramatically, and commercially orientated production of parrots now involves hundreds of thousands of parrots annually from a wide diversity of species. Despite this growth, our review of the most frequently traded threatened species showed a surprising dearth of research with which to evaluate the potential of captive production as a supply-side intervention to take pressure off exploited wild populations. Moreover, we found evidence of multiple ways in which trade in captive-bred parrots is stimulating and facilitating trade in wild-sourced parrots, which may be unsustainable as well as illegal and otherwise harmful. This raises concerns about the assumptions underpinning existing policy approaches at both national and international levels that frequently facilitate the mass production and international trade of many threatened and nonthreatened parrots.

Research trends and key knowledge gaps

Across the criteria, the majority of sources we identified contained anecdotal information or expert knowledge addressing topics including consumer preferences, changing markets, breeding difficulty, challenges with profitability, and the risks of genetic loss. Such information is valuable for providing insights into the practical conditions from different perspectives in specific contexts (e.g., Ortiz-von Halle et al., 2018) and for generating hypotheses that can then be rigorously investigated and tested. However, we identified a general lack of analyses of empirical data for evaluating the criteria, with the exception of evidence of laundering and analyses of source composition in CITES trade data and market surveys (Table 2).

TABLE 2. Summary of key evidence gaps identified in the literature review regarding commercial captive breeding of parrots as a supply-side conservation strategy.

Evidence gap
Demand for wild-sourced birds as breeding stock in developing parrot markets
Quantitative data on aviculture market dynamics over time
Comprehensive quantitative data on species' productivity in commercial breeding facilities, relative breeding difficulty, and relevant life-history traits based on current best practice.
Quantitative assessment of profitability across species and countries with current breeding practices.
Impacts on profitability of commercial breeding operations of measures to prevent laundering of wild sourced parrots into captive-bred supply chains
Demand among commercial breeding operations for wild sourced breeding stock to address perceived effects of inbreeding and genetic loss
Extent and impact of inbreeding depression and genetic loss among commercial breeding operations
The extent and impact on wild populations of laundering of wild sourced parrots through captive-bred supply chains

It was particularly striking to find very few published sources over the past decade, especially regarding information on cost-efficiency under different settings (criterion 3; $n = 1$) and the need for and sale of restocking in commercial breeding (criterion 4; $n = 0$). This lack of recent research attention is important because much of the information needed to evaluate all criteria may change over time or between geographical contexts. For example, levels of demand and consumer preference may change in response to levels of disposable income as well as changing knowledge, attitudes, and social norms regarding conservation, welfare, and parrot

ownership. The recent penetration and the expansion of social media are amplifying many trends and further driving the development of new markets (Davies et al., 2022). Levels of supply can also change dramatically over time—for example, the development of new husbandry techniques or technology may make some species easier to breed and rear in captivity, driving down costs and increasing levels of production. For example, although articles published before 2012 suggest that macaws are generally difficult to breed, more recent expert opinion suggests that some species like the blue-and-yellow macaw (*Ara ararauna*) can be prolific breeders in captivity (C. Senni, personal communication, 2023). Changing regulations and changing implementation of law enforcement may additionally affect levels of supply. As a result of these rapidly changing circumstances, there is a need for continuous data collection and regular evaluation of the evidence to support adaptive management.

One of the biggest data gaps was the lack of objective, quantified, and current estimates for the breeding productivity of different parrot species from commercial breeding facilities using current practices, considering both reproductive capacity and mortality rates. Levels of breeding productivity vary considerably between species, breeding systems, available technology, and knowledge of husbandry techniques. Several resources currently provide data on life history and reproductive success of parrots (www.Species360.org; Young et al., 2012), but these tend to be based on wild populations or breeding in zoological facilities, which will differ from commercial productivity. Data on breeding capacity have been absent from recent data summaries (VKM, 2020) or limited to records in the Zoological Information Management Systems maintained by Species 360 and anecdotal expert knowledge (Furnell & Jain, 2019), whereas the absence and urgent need for these data have been noted in action plans for cape parrots (Carstens et al., 2020) and yellow-crested cockatoos (Prijono, 2008).

The lack of objective assessments of realistic levels of production in captivity for different species has been a major challenge for identifying implementation issues with trade in captive-bred birds under CITES; avicultural experts disagree on the ease with which certain species can be bred (R. Martin, personal observation). In Brazil, limits placed on production levels for birds bred in captivity are based on years of learning to prevent laundering but are perceived as unrealistically low by the breeders' association (Ortiz-von Halle et al., 2018). Establishing robust and current data for each species is critical for assessing the potential value and impact of captive breeding and the design of effective policy but is a complex challenge given vested interests, lack of trust, and differences in avicultural knowledge between stakeholders. A constructive dialogue and regular systematic surveys of multiple experts with diverse backgrounds in husbandry and captive production systems, including avicultural interest groups and zoological collections, could help determine realistic levels of production in specific circumstances. Such a process has recently been used to evaluate the difficulty of captive breeding of songbirds, with species placed in one of 4 categories of difficulty based on the need

for specialist technology and expertise (Juergens et al., 2021). A similar approach might also help evaluate perceived and real benefits, from the introduction of wild specimens into captive collections to prevent inbreeding depression and maintain productivity. Although benefits of introducing birds from the wild into captive collections are assumed by some aviculturists, we found no studies in the last decade concerning any of our focal species that sought to empirically evaluate productivity loss due to inbreeding depression within the context of commercial captive breeding or evaluate how simple pedigree management techniques could mitigate any negative effects. A recent review of genetic methods in the study of parrot biology and conservation (Olah et al., 2021) identified a single study, over 25 years old, that evaluated the effects of inbreeding on fitness characters in Budgerigars, finding conflicting results across 2 breeding programs (Daniell & Murray, 1986). Olah et al. (2021) highlighted a number of studies examining the effect of inbreeding on immunocompetence in parrots, but the relevance of such studies to commercial systems was not clear. In addition to filling this evidence gap, investigations into the extent to which inbreeding is perceived as a problem, driving demand for wild-sourced parrots among aviculturists, would also help develop interventions to address demand for wild-sourced parrots from commercial aviculture.

Cost-effectiveness is the most complex criterion to address because it is affected by a range of factors, particularly the source of breeding stock (Clubb et al., 1992; Dennison, 2004) and the effect of monitoring and regulations. Objections to marking systems, monitoring, and regulation have been made on the basis that they make breeding unprofitable (Ortiz-von Halle et al., 2018; R. Martin, personal observation). In the only quantitative analysis of profitability identified in our search, Dennison (2004) analyzed the economic model underpinning breeding farms for gray parrots in South Africa, where wild-sourced parrots were used as breeding stock. Prior to the transfer of gray parrots to Appendix I of CITES, South Africa was the leading importer of wild-sourced gray parrots, as well as the leading exporter of those bred in captivity (CITES, 2017; Martin, 2018). The source of wild gray parrots shifted from West to Central Africa (Mulliken, 1995) as populations collapsed due to overexploitation (Annorbah, 2016; Hart et al., 2016) and additional regulations put in place (Martin, 2018). Since 2017, captive-breeding operations in South Africa can no longer legally import wild-sourced gray parrots to supply farms. It is unclear based on current research how a shift to captive-bred breeding stock has affected production costs and resulting prices, given that gray parrots take several years to reach reproductive maturity. Concerns have been raised, both in the past and recently, of South Africa importing parrots that were wild sourced and illegally trapped (de Greef, 2016; Mulliken, 1995). It is essential that economic analyses similar to that conducted by Dennison (2004), who assessed the viability of legal and sustainable production of parrots, consider the full costs of monitoring and enforcement systems to ensure trade does not negatively affect wild populations through noncompliance.

Across all criteria, there is an urgent need for information and data from markets where demand and captive breeding are increasing rapidly, such as southern and southeast Asia and the Middle East. Growing affluence, cultural shifts, and access to the internet have resulted in greater demand for exotic pets in new markets (Bush et al., 2014; Challender et al., 2015), which in turn creates new trade "ecosystems" (Jain et al., 2022) of hobbyists, commercial breeding enterprises, and consumers. Many of the sources we came across were not only dated but also biased toward geographical areas that have been the historical centers of commercial trade in parrots, meaning that it is unclear whether early observation, such as a preference among breeders for wild-sourced birds, or difficulties in achieving profitability still hold true in new growing parrot markets. Several studies explored the drivers of trade in parrots through comparisons of trade in different species to disentangle the roles of supply-side and demand-side factors (e.g., Tella & Hiraldo, 2014; Pires, 2015; Pires et al., 2021). These studies drew conflicting conclusions, suggesting that the drivers are complex and depend on the geographical and cultural context. This information has major implications for whether captive breeding in these countries reduces demand for wild-sourced parrots or increases it through demand for stock and by increasing overall demand. Recent research in parrot trade in Singapore demonstrates how investigations into growing parrot markets can obtain useful qualitative data from multiple actors (Aloysius et al., 2020; Jain et al., 2022), and similar approaches should be adopted in other countries.

Strengthening frameworks for the evaluation of wildlife farming as a supply-side intervention

We adapted a framework proposed by Tensen (2016) based on 5 criteria, which were in turn derived from those proposed by Biggs et al. (2013). Although these criteria provided a useful conceptual framework with which to evaluate the quantity and quality of evidence in key areas, we found the existence of complex interactions and trade-offs between criteria that can make the implications of violations for the exploitation of wild populations difficult to evaluate. These interactions may counteract or reinforce each other as illustrated in Figure 5. For example, parrot owners being prepared to pay more for captive-bred birds may relax the need for captive breeding to compete on price with wild-sourced birds (Figure 5a). Elements necessary for sustainable captive breeding may also be antagonistic, making it difficult to achieve both criteria. For example, the regulatory mechanisms necessary to prevent or reduce laundering to a sufficiently low level may increase costs for captive-breeding operations and make them less cost-effective (Figure 5e). We propose that future evaluation frameworks should carefully consider interactions between criteria.

Toward informed and evidence-based interventions

Despite the scale and scope of captive breeding of parrots that exist today, we found a remarkable dearth of information available to policy makers and conservation practitioners on which to base decisions that could be hugely consequential for wild populations of parrots. Moreover, we found that multiple criteria were violated, raising numerous red flags concerning the current largely permissive regulatory regimes that structure this type of international and domestic trade.

Our review identified several important areas that pose particular challenges to conservation-focused policy makers and practitioners. First, major differences exist between species and circumstances in the extent to which captive breeding may be able to relieve pressure on wild populations. Although it seems likely the production in captivity of some species in some circumstances (e.g., budgerigars and cockatiels) may no longer be detrimental to wild populations of those species, production in others can pose serious direct and indirect threats to wild populations. Because current species- and context-specific information on many threatened species is lacking, decision makers may be tempted to make inferences on likely outcomes based on situations for other species, countries, and contexts, unaware of the risks involved in doing so. It is therefore essential to ensure decision makers are well informed of the limitations of existing knowledge for specific situations and the complexities underlying differences between species and contexts.

Second, complex interactions exist between trade in different species of parrots, and indeed other birds and live animals. The phenomenon of upgrading, whereby people journey from the purchase of relatively cheap and available animals toward rarer, larger, and more expensive species, means that regulations for each species cannot be considered in isolation. Permissive environments for some species may normalize and encourage the ownership of parrots leading to unanticipated growth in demand for more threatened species. The emergence of social media may have supercharged this phenomenon (Jain et al., 2022). Countries where there is limited capacity for ensuring compliance with regulations may struggle to control this rise in demand, particularly as restricted and threatened species can be misdeclared, either internationally or through ignorance, or smuggled among less controlled species. Effective interventions must carefully consider the interactions between trade in species, taking a broad taxonomic approach rather than focusing on individual species in isolation.

Third, although it is evident that greater effort is needed to understand, monitor, and regulate commercial trade in captive-bred parrots, policy makers will need to decide where the burden of proof lies for demonstrating that captive trade can supply demand and will not have a negative effect on wild populations. This is particularly important regarding parrot reproductive capacity, restocking practices, and measures against laundering. For instance, over 200 operations for producing gray parrots are registered with CITES and export thousands of parrots each year, generating substantial profits. Despite concerns that this trade is both

directly and indirectly driving trade in wild parrots, current regulatory mechanisms do not require the industry to monitor its effects or demonstrate sustainability. As the trade in captive-bred parrots increases, opportunities for laundering wild parrots into captive-breeding facilities as breeding stock or for sale to end consumers are also expanding rapidly. Although the technology exists to determine the provenance of parrots in trade (e.g., Alexander et al., 2019), there remains an implementation gap. Measures to prevent laundering, such as genetic testing of parentage and proof of legal acquisition of breeding stock, have been opposed by some industry groups because the administrative burden would make parrot farming less profitable (R. Martin, personal observation). The costs of monitoring the impacts of trade are often externalized by industry, and instead, the burden frequently falls on governments or nonprofit organizations, often with little capacity and resources to do so. Conservation-focused policy makers must similarly consider how the proceeds of wildlife trade can be equitably shared to prevent the costs and impacts of illegal and unsustainable trade being felt by communities on the front line, whereas the benefits are accrued to relatively wealthy farm owners in other countries.

Finally, although not a focus of our review, policy makers must also carefully consider the other risks posed by the commercial captive breeding of parrots, including impacts on the welfare of the parrots involved, the spread of infectious diseases of zoonotic and conservation concern (which are often exacerbated by poor captive conditions), as well as the spread of invasive species that can also have significant economic impacts (D'Cruze et al., 2020). Breeding facilities have been identified as a key location for transmission and recombination of infectious viruses (Bért et al., 2005; Cassey et al., 2004), and others have recommended improvements to biosecurity measures (Aloysius et al., 2020; Jain et al., 2022). Whether an adequately regulated system, which avoids these harms, throughout the supply chain, while remaining economically viable, can be designed remains an open question. This type of decision-making should also consider that in some markets, public understanding, attitudes, and ethical standards are evolving to the extent that these potential negative impacts of commercial captive breeding are becoming increasingly socially and culturally unacceptable (Wyatt et al., 2022). Dismantling a captive-breeding industry once established can present significant practical and ethical challenges when dealing with large quantities of live and long-lived animals, which were formerly used as breeding stock.

In conclusion, we emphasize the existence of major uncertainties and numerous red flags regarding the commercial production of parrots as an effective supply-side conservation measure and highlight the risks posed to wild populations as this trade rapidly expands. As a minimum step, we concur with others that have called for greater research, monitoring, and regulation to prevent laundering and ensure sustainability of captive breeding of parrots for commercial purposes (Aloysius et al., 2020; Chan et al., 2021; Eaton et al., 2017; Sánchez-

Mercado et al., 2021). We urge policy makers to carefully consider regulatory frameworks for commercial trade in captive-bred parrots to ensure unintended consequences are avoided. With the scale of global trade in captive-bred parrots reaching record levels and major economies, such as China, on the cusp of relaxing laws on the domestic production, and a number of countries, like South Africa, actively engaged in commercial captive breeding of endangered parrot species, there is an urgent need to treat the commercial production of threatened parrots with caution to prevent the further collapse of wild parrot populations.

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Supporting Information

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