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Tools and terms for understanding illegal wildlife trade

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Abstract
Illegal wildlife trade (IWT) is a targeted threat to thousands of species globally, including fish, fungi, medicinal plants, charismatic mammals, and many others taxa. Despite widespread recognition of the problem, academic and policy debates are dominated by a few high-profile species (e.g., rhinoceros, tigers, elephants), and often overlook or conflate complex IWT products, actors, networks and contexts. Imprecision in our understanding of IWT is aggravated by a lack of vocabulary and frameworks to dissect complex phenomena in a structured way. We synthesize the available evidence on IWT across taxa and geographies into a typology-based framework that considers 1) the diversity of wildlife products; 2) IWT actor roles related to the harvesters, intermediaries and consumers; and 3) common IWT trade network configurations. We propose how these tools can inform structured analyses of IWT, to inform more nuanced, appropriate, targeted and effective responses to illegal wildlife harvest, trade and use.

Caricature of a biodiversity crisis

Illegal wildlife trade targets thousands of species of terrestrial and marine animals, plants, and fungi worldwide (IUCN 2012), with cascading impacts on the environment, livelihoods, food security, national security and sustainable development (e.g., Oldfield 2003; Dickson et al. 2008; USA 2014; Brashares et al. 2014; NOAA 2016). While trade in many taxa is legal and regulated, escalating illegal trade is of increasing conservation concern globally. IWT has attracted renewed societal, media and political attention, as well as hundreds of millions of dollars in additional investment, largely in response to dramatic increases in elephant and rhinoceros poaching (Duffy and Humphreys 2014; UW 2014; Sutherland et al. 2014).

There are growing scientific and policy debates over which types of conservation interventions are most effective, including increased enforcement, demand reduction strategies, provision of alternative livelihoods, market-based and incentive-oriented approaches (e.g., Biggs et al. 2013; Sutherland et al. 2014; Duffy 2014; Bennett 2015). The diversity of proposed interventions reflects the complexity of IWT, yet

practitioner and policy debates often approach IWT as simple and monolithic (cf. Österblom et al. 2011; Brashares et al. 2014). For example, taxonomic biases mean that a few charismatic species are often treated as representative of broader IWT (e.g., elephants, rhinos, tigers, UW 2014; Sutherland et al. 2014), while the vast majority of traded species are overlooked (cf. Nijman et al. 2012). Similarly, IWT discussions often classify diverse actor roles and motivations into simplistic categories of "poachers", "perpetrators" and "criminals" (Duffy 2014; e.g., UK 2014; USA 2014; Douglas and Alie 2014). Diversity is further obscured by a growing focus on organized criminal syndicates in the trade of some taxa, which overlooks more pedestrian forms of wildlife trade and use (Duffy 2016; see Pires 2012; e.g., Bennett 2011; Douglas and Alie 2014; USA 2014).

Indeed, illegal systems are often difficult to study directly, and so it is unsurprising that many policies underappreciate patterns and nuances (cf. von Lampe 2012). However, lessons from the drug trade highlight the limitations of interventions based on popular misunderstandings about illegal trade dynamics. Broad assumptions about how trade is organized and responds has led to policies that overlook the underlying causes of trade; fail to anticipate unintended consequences such as social impacts and undesirable price signals, and tend to overlook the resilience of trade networks to enforcement (see Williams 1998; Kenny 2007; LSE 2014).

Imprecision in IWT study and debate is also aggravated by the lack of vocabulary and frameworks to dissect IWT phenomena (see South and Wyatt 2011). There is clear need for tools to navigate the diversity of products, actors, networks and contexts that comprise IWT in a way that is structured and comprehensible (cf. Ostrom 2009; Laird et al. 2010; von Lampe 2012). Shared lexicon would allow for more nuanced and productive dialogue, and improve formulation of research and conservation interventions.

We review IWT across taxa, contexts and geographies, drawing from the IWT literature and field experience in order to (1) define IWT products; (2) present a typology to characterize key IWT actor roles; (3) understand common IWT network configurations, and (4) illustrate how these typologies can facilitate structured analysis of IWT interventions.

Defining IWT products

IWT involves the harvest, trade and use of wild, biological specimens for uses ranging from food to ornaments to construction (Table 1). It affects a wide range of flora, fauna and fungi, and both live specimens and various wildlife products needed or valued by consumers. Notwithstanding that some forms of wildlife trade are legal, IWT is characterized by actions that contravene stated environmental regulations, including government legislation, rules governing private/community resource-holder rights, and/or international agreements (e.g., Convention on the International Trade of Endangered Species of Flora and Fauna, CITES). Equally, however, many instances of harvest and trade are unsustainable from an ecological perspective, but are not necessarily illegal.

Despite a tendency to associate IWT with a narrow range of taxa, trade affects thousands of species, including timber, marine species (i.e., Illegal, Unreported, and Unregulated Fishing), small mammals, insects, plants and reptiles (IUCN 2015; cf.

Laird et al. 2010; Nijman et al. 2012). Importantly, single species often provide multiple products that may enter completely different value chains (e.g., medicinal versus ornamental orchids). In addition, different forms or sources of a single product may be legal, while others are illegal (e.g., farmed versus wild-collected specimens; organisms collected within or outside of official quotas; individuals traded domestically versus internationally).

Characterizing IWT actors

IWT involves a range of actors in harvest, trade and use dimensions. Actors differ not only in roles they play along market chains, but in their personal attributes, preferences and motivations; different scales of operation and intensities of harvest; levels of technological investment; sources of funding, levels of economic reliance, and knowledge, including of associated regulations (see Muth and Bowe 1998; Eliason 1999; Wyatt 2009; South and Wyatt 2011; Duffy et al. 2015).

Our typology distinguishes roles played by ***harvesters***, ***intermediaries*** and ***consumers*** that, while not mutually-exclusive, categorize key patterns across IWT situations (Table 1; Fig. 1). Actors can participate in multiple roles, with a wide range of motivations that are both context and value-dependent, and change over time (see South and Wyatt 2011; Duffy et al. 2015). For example, some actors are highly specialized and focus on target specific taxa, while many are more generic (e.g., wild meat, fish). While illegal wildlife harvest and consumption are often characterized as the result of economic poverty or greed, motivations are often far more complex (see Duffy et al. 2015); even among comparatively poor communities, wildlife consumption can be associated with preferences, stature, and higher incomes (e.g., Mbete et al. 2011). Similarly, harvesters may be poor in absolute terms, but well off in comparison to their neighbors, where IWT represents better economic prospects than alternative opportunities (e.g., Vira et al. 2014).

Wildlife harvesters

We distinguish among eight broad categories of harvester roles (Table 1; Fig. 1). ***Subsistence harvesters*** are primarily engaged in collection of wild resources for household or non-commercial local uses (e.g., Golden et al. 2013). However, subsistence activities often overlap with more ***specialized commercial harvest***. For example, in Central Vietnam's Thua Thien Hue Province, forest-accessing communities often use snares in subsistence harvest, although some residents also use targeted, specialized cages to trap stump-tailed macaques (*Macaca arctoides*) to supply luxury urban markets. Similar combinations of subsistence and commercial harvest exist among the Waorani communities in the Ecuadorian Amazon (see Example 3, below).

Both subsistence and commercial markets can also involve ***opportunistic harvest***. In Central Vietnam some residents also opportunistically fell fruiting trees of *Scaphium lychnophorum* to harvest fruits for international markets (ELW, pers. obs.). While commercially-motivated, this is neither a regular nor primary livelihood, which are often overlooked in IWT discussions (Eliason 1999; Muth and Bowe 1998; Pires 2012).

Table 1. Typology of key actor roles along IWT market chains. Categories are not mutually exclusive.

Harvesters	
Subsistence	Non-commercial harvest for household or local use (e.g., food, cultural, see list below), usually comparatively small-scale
Specialist commercial	Harvest with an explicit commercial orientation that often involves specialist skills or technologies. Includes different harvest intensities, levels of technological investment, and is led by both self-employed and hired harvesters, and by local residents and outsiders
Opportunist	Harvest based on chance encounters and circumstances, but not as a primary objective or livelihood strategy
Local guide	Local residents hired to guide outside harvesters
Rule abuser	Knowing abuse of harvest rules, such as quotas (e.g., under or mis-reporting), boundaries (e.g., protected area) or restrictions on technology (e.g., certain traps, nets)
Bycatch	Unintentional harvest of non-target species
Recreational	Harvest for enjoyment
Reactionary	Harvest associated with discontent or protest (e.g., in reaction to conservation policies or conflict with wildlife)
Intermediaries	
Logistician	Involved in ordering, aggregation and transport, as well as financing and planning trade. May be directly involved in handling trade or involved at a distance.
Specialized smuggler	Transport that requires specialized actions to evade detection or negotiate access (e.g., transboundary smuggling, specialist networks)
Government colluder	Involved in using an official government position (park ranger, police officer, judge, prosecutor) to facilitate trade, whether for financial (corruption), social or personal gain
3rd party	External services hired to support trade, but potentially unknowingly (e.g., bus or air transport)
Processor	Involved in product transformation (e.g., skinning, medicine preparation)
Launderer	Involved in laundering illegal wildlife into legal markets chains (e.g., via captive breeding or processing operations)
Vendor	Involved in direct sale to consumers or to other intermediaries (e.g., market, online platform)
Consumers	
Medicinal	Use associated with medicinal practices, usually traditional but some novel
Ornamental	Use associated with ornaments and pets (e.g., ivory, shell, live parrots, aquarium fish)
Cultural	Use associated with long-standing traditional practices (e.g., feathers, pelts, ritual harvest)
Gift	Use as a gift, often to gain/demonstrate social standing or show respect
Investment	Use as an investment, usually of high-value taxa
Recreational	Use associated with the act of recreational harvest (e.g., game hunting, sport fishing)
Animal food	Use as food for other animals (e.g., fodder, bait, small animals)
Construction materials	Use for construction materials (e.g., timber, rattan)
Fuel	Use for burning for heat or cooking
Food	Use for direct consumption, ranging from luxury consumption to basic nutritional need

However, ***specialized commercial harvest*** often requires sophisticated technologies, networks, funding and coordination. At the extreme, harvest of high-value taxa (e.g., tigers, rhinos, shark fins, birds of prey, hardwood timber) often involves external professional harvesters, criminal syndicates and connections to political elite. These may hire local residents to harvest or guide outside harvesters (***local guide***, e.g., Wyatt 2009; GW 2007; Bennett 2011). Recent African ivory seizures highlight the ability of these commercial harvesters to adapt to increasing enforcement (Milliken 2014; Vira et al. 2014).

Illegal harvest can also occur when harvesters break the rules associated with *legal* harvest systems (***rule abuser***). For example, the abuse of allocated harvest quotas in

the fishing and timber sectors, the use of illegal technologies such as snares or dynamite fishing, and harvest within protected area boundaries can convert otherwise legal harvest into illegal goods (e.g., Hatcher and Gordon 2005; Radjawali 2011). Similarly, accidental ***bycatch*** of protected species, such as due to harvest using snares or nets, can represent illegal takes.

Illegal harvest can also be associated with ***recreational activities***, or can represent a defensive response to conflict with wildlife, such as crop raiding that affects rural livelihoods, or opposition to conservation policies (***reactionary harvester***, Muth and Bowe 1998; Oldfield 2003).

Figure 1. Diverse types of IWT harvesters. (a) Subsistence harvester with porcini mushroom (*Boletus edulis*) collected without permits in Forli Province, Italy (Credit: D.Galli). (b) African elephant (*Loxodonta africana*), widely targeted for ivory across its range by specialist commercial harvesters, often with support of local guides (Credit: P.Mannix). (c) Inspection of a fishing vessel in the Gulf of Guinea suspected of abusing fishing rules (Illegal, Unreported, and Unregulated Fishing, Credit: K.Akuamoah-Boateng).

Trade intermediaries

Moving wildlife to consumers typically relies on actors generically described as "middlemen", although these *intermediaries* in illegal networks can serve diverse and complex roles (cf. UNODC 2002). They often work as ***logisticians*** involved in moving goods in ways that require specific contacts, networks and skills (Warchol 2004; Wyatt 2009). They may be directly involved in ordering and handling illegal goods, or may be more distantly associated through financial links or coordinating logistics for others (e.g., Milliken and Shaw 2012; Milliken 2014). Because accessing markets for illegal products can be challenging and high-risk, intermediaries are often critical to facilitating access across international borders (***specialized smuggler***), including by bribing or working with government agents (***government colluders***, e.g., Fig. 2, 4a; Pires 2012; Vira et al. 2014). However, in some instances, intermediaries may be ***3rd parties*** that are unaware of their roles, as in the case of airlines or bus companies (TRAPS 2015).

Intermediaries may also engage in physical transformation of wildlife, such as cleaning, butchering, skinning, or preparing medicines (***processors***, *e*.g., Vira et al. 2014). This may require specialized skills or infrastructure, such as sawmills for timber. Intermediaries may also provide laundering services that integrate illegal products into mainstream legal value chains (***launderers***), as has been documented among farms that claim to raise porcupines for meat (Brooks et al. 2010), reptiles and birds for pets (Fig. 4) and timber for furniture (GP 2014). Most visibly, intermediaries also include consumer-facing ***vendors*** and their associated platforms (e.g., public markets, online platforms).

Wildlife consumers

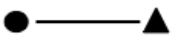
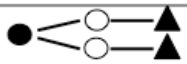
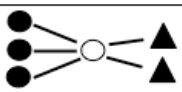
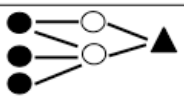
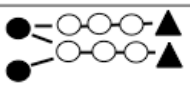
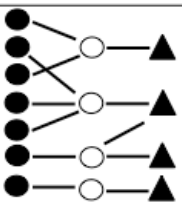
Consumer uses of wildlife are as diverse as the of taxa illegally traded (Table 1). Public attention is often on ***medicinal*** use, particularly of charismatic taxa for Traditional Asian Medicine. However, thousands of other species are also used as medicines globally (Laird et al. 2010; Nijman et al. 2012), and many taxa have other, complex social meanings and diverse uses (see Courchamp et al. 2006; Truong et al. 2015). Wildlife and their parts can have ***ornamental*** uses, including as pets (e.g., Wyatt 2009; Pires 2012), can serve as ***cultural*** objects (e.g., De Angelis 2012), and/or be used as high-value ***gifts*** or ***investments*** (e.g., Gao and Clark 2014; Truong et al. 2015). Wildlife may also be used in activities where harvest itself is a ***recreational*** or ***cultural*** act (e.g., Muth and Bowe 1998). Some wildlife are also used as ***animal food*** to feed captive/domesticated animals (Naylor et al. 2000), for ***construction materials***, and as ***fuel*** (e.g., charcoal, Wyatt 2013). Importantly, many taxa are used for ***food,*** both to meet basic nutritional requirements and as luxury products due to a range of consumer preferences (e.g., Example 3, below).

Consumers may be present anywhere along the market chain, including at or near the point of harvest, in association with transport, or at defined end-markets, restaurants or online portals. Illegal transactions may occur in open markets or in secret, including through secret transactions, through the anonymity of online sales, or through the laundering of wild products (e.g., Fig. 4). Importantly, downstream consumers are not necessarily aware of the origins of wild products (e.g., Fig. 2, 4) or of related regulations (e.g., GP 2014).

Understanding IWT networks

Actors in IWT are configured into diverse network configurations (cf. UNODC 2002; Kenney 2007), of which we identify seven common structures (Table 2). Their architecture ranges from simple relationships, such as ***subsistence and local use*** relationship, or a structure that links ***harvesters directly to consumers*** (Table. 2a,b), to configurations that involve multiple intermediaries. Much of this complexity arises from restrictions to access, whether to the resource itself, transport routes or to consumers—including to distant urban or international markets willing to pay higher prices.

Table 2. Typology of common IWT network configurations, linking wildlife harvesters (black circles), intermediaries (white circles) and consumers (triangles). These can refer to both the structure of entire networks, or to the "building blocks" of more complex, compound networks.

Type of network	Illustrative architecture (harvesters – intermediaries – consumers)	Explanation
a) Subsistence and local use		Harvest principally for household or very local use
b) Harvester directly to consumer		Harvesters have direct market access, usually due to geographic proximity
c) Restricted resource access		Resources access at source is limited by species distribution, a requisite harvest technology, user group rights, and/or enforcement
d) Gatekeeper		Market access is limited by a small number of intermediaries, potentially because of their ability to circumvent legal restrictions, access to technology, or market monopolization
e) Restricted market access		Market access relies on a limited number of sites or platforms (e.g., markets, Internet sites)
f) Multiple barriers to market		Market access limited by multiple barriers, such as geographic distance, high enforcement and/or processing demands
g) Redundant pathways		There are few barriers to participation in illegal trade, potentially because resource is abundant or widely distributed, and/or enforcement is low

A network configuration ***restricted by resource access*** is defined by trade structured around a specific geography and/or limited set of harvesters (Table 2c). For example, the Lao Newt (*Laotriton laoensis*) is endemic to high elevation streams in a small part northern Laos. As a result, international collectors have relied on local residents with species knowledge and access to harvest newts for the pet trade (Phimmachak et al. 2012).

Gatekeeper configurations arises when a limited number of intermediaries control market access, based on the provision of pivotal services, contacts or capital that enable them to overcome transport, enforcement or technical barriers (Table 2d). For example, the illegal timber trade in Pará, Brazil relies on central mills that provide timber processing and avenues through which to launder illegal timber into legal supply chains (GP 2014). Similarly, the Indonesian reptile trade requires specialized knowledge, contacts and access to permits to enable international trade (Fig. 4). The

live reef fish trade uses expensive technologies to keep fish healthy and attractive until they reach overseas restaurants (Radjawali 2011). Such centralized structures are also likely where criminal syndicates exclude other participants through force (Bennett 2011; Milliken 2014).

Trade networks can also be ***restricted by market access*** that mediate consumer access (Table. 2e), such as specific stores, neighborhoods, markets or online portals to which trade is restricted, forcing or enabling certain patterns of trade interactions. Restrictions may require several linked intermediaries (Table 2f) to enable transport, evade enforcement, pay bribes, and/or leverage social networks to enable trade across protected area boundaries, police checkpoints and international borders (***multiple barriers to market*****,** e.g., Radjawali 2011; Vira et al. 2014; Phelps 2015). Structures with ***redundant pathways*** are characterized by complex web-shaped configurations, are the result of few barriers to participation in harvest and/or access to market (Table 2g). These networks involve widespread participation and exchanges among a larger number of individuals and are more likely where enforcement is weak.

Trade frequently involves compounded networks that integrate multiple configurations (Table 2). For example, Southeast Asia's trade in wild, ornamental orchids affects hundreds of species and involves surprisingly complex trade networks (Fig. 2; WebPanel 3).

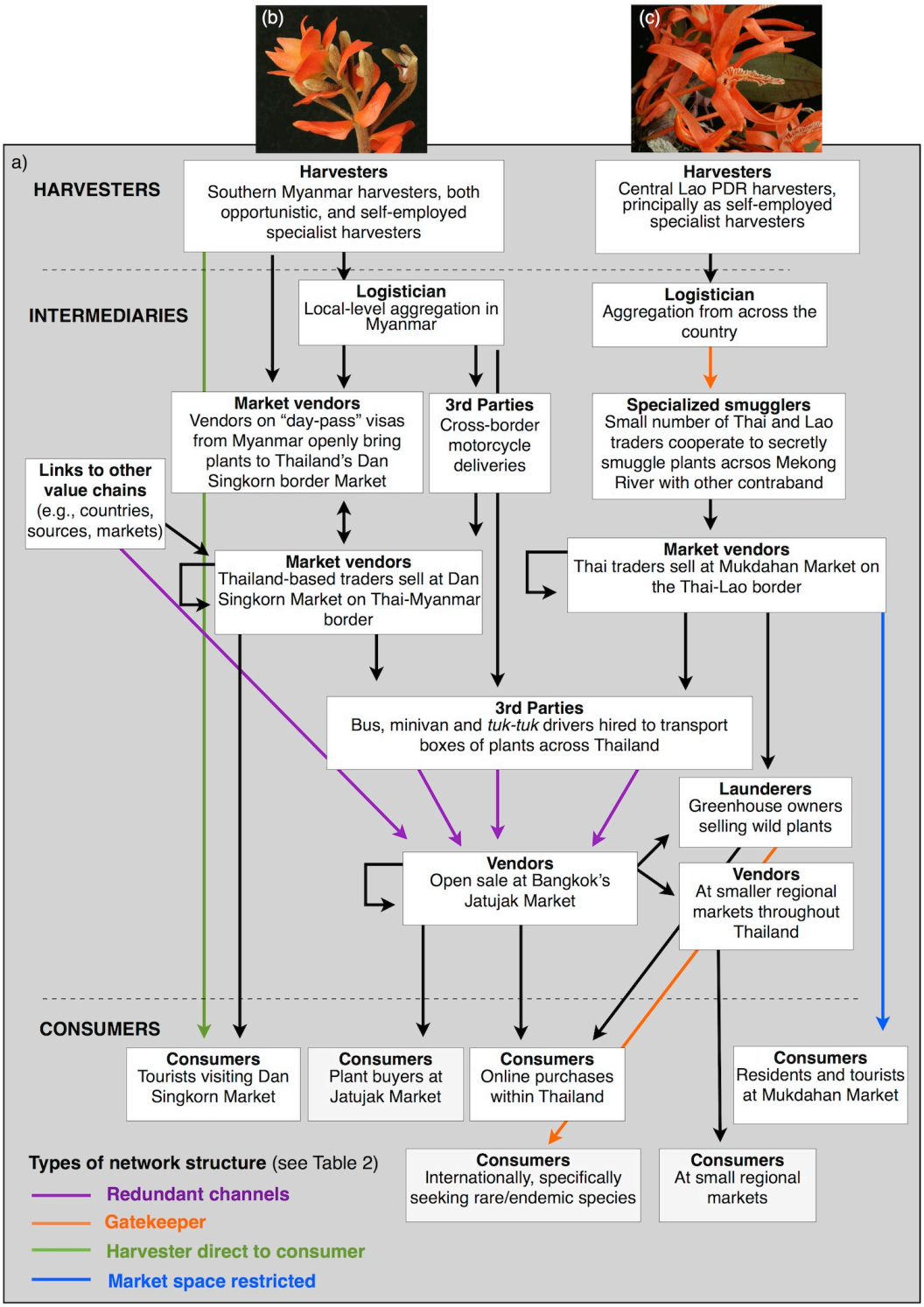


Figure 2. Network of illegal trade in protected ornamental orchids harvested in Southeast Asia. (a) Overview of trade network of plants from Lao PRD and Myanmar for sale in Thailand and internationally, including the roles of harvesters, intermediaries and consumers (Phelps and Webb 2015; Phelps 2015). Colored lines illustrate selected examples of trade network structures (see Table 2). (b) Ornamental orchid (*Eria ornata*) commonly harvested in Myanmar. (c) Ornamental orchid (*Dendrobium lamyaiae*), a narrowly-distributed (possibly endemic) species harvested in Lao PDR.

Beyond actor and network mapping, understanding IWT requires evaluation of the contexts that shape actors' decisions--determining actual and perceived rewards, effort, preferences and risks associated with illegal behavior (Ostrom 2011; e.g., WebPanel 1). These include biological characteristics, such as species abundance, distribution and fecundity, and physical variables such as topography, seasonality and infrastructure. The factors affect access to wildlife, as well as effort and profitability from IWT. Decisions are further shaped by governance context, such as the legal-regulatory framework and the effectiveness of enforcement, which shape the secrecy and effort involved in harvest, processing and transport; the sanctions of getting caught, and perceived legitimacy of rules (e.g., Moreto and Lemieux 2014; South and Wyatt 2011). Decisions are also defined by social context, including individual agency (Duffy et al. 2015), relationships to specific wildlife products (e.g., Gao and Clark 2014), knowledge about where to find wildlife, and levels of trust, fidelity, transparency and benefit sharing among actors (e.g., Radjawali 2011; cf. McGloin and Kirk 2010).

IWT actors and networks are dynamic; they adjust to changes in biophysical parameters (seasonality, weather, abundance), market pressures (price increases) and governance contexts. For example, some consumers' preferences for rarity can simultaneously increase harvest pressure and increase rarity (Courchamp et al. 2006). Changes in enforcement actions can yield novel interactions (cf. Williams 1998). For example, increased enforcement seems to have led to new configurations in Russia's falcon trade (Wyatt 2009), and to a shift to online sales in China's ivory trade (Gao and Clark 2014).

Implications for conservation and illustrative examples

Trade dynamics are the function of interactions among products, actors, and networks, themselves embedded in a range of biological, physical, governance and social contexts (Fig. 3). These factors not only interact but also shape how different conservation interventions play out, including likelihood of success and unintended outcomes.

Faced with this complexity, a typological approach has potential to help us consolidate languages and concepts across taxa and contexts. It is particularly useful in the context of limited ecological data, conservation resources, uncertainty and contention over the most appropriate interventions, in order to facilitate policy debates, inform research and craft more nuanced, socially appropriate, fair and effective interventions. The following taxa examples highlight parts of a typology-based framework (see also WebPanel 2), and how it can be used to inform interventions, with each species also benefitting from full evaluation (e.g., WebPanel3).

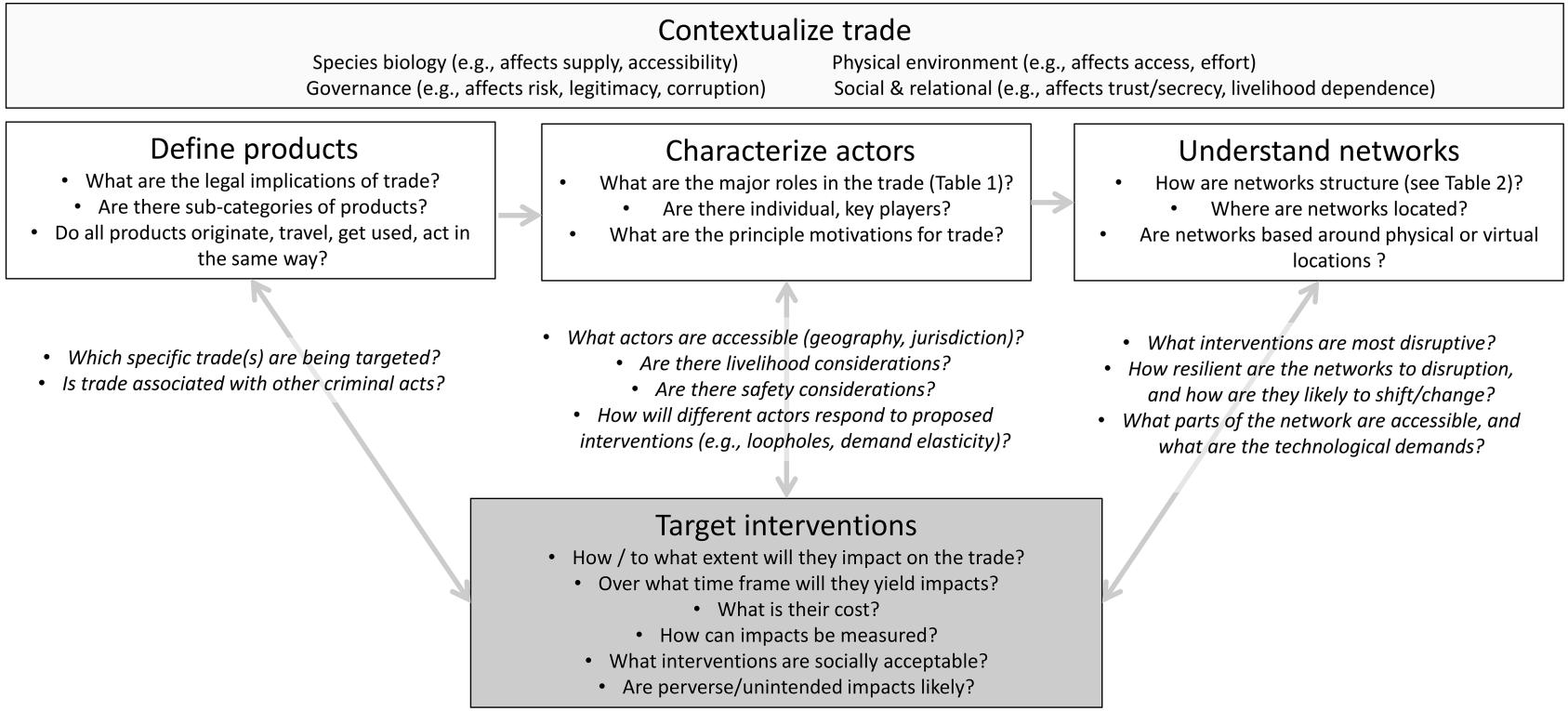


Figure 3. Framework for evaluating IWT interventions to consider contextual parameters, products, actors (Table 1), networks (Table 2), and their relationships to conservation interventions. (The framework is expanded in WebTable1.)

Example 1: Defining products - Southeast Asian orchid products

Commercial trade is an intense, targeted threat to many Southeast Asian orchid species (Fig. 2) 3; Phelps 2015; Phelps and Webb 2015). Conservation efforts have traditionally focused on restricting international trade, although these rules are widely disregarded (Phelps and Webb 2015). Structured IWT analysis (Fig. 3) highlights opportunities for strengthened interventions, including based on an improved understanding of orchid products themselves.

Although superficially similar, orchid trade shows non-trivial differences (in consumer preferences, prices and networks) between relatively common ornamental species, and the trade of rare and endemic species targeted by specialist consumers (Phelps 2015; cf. Hinsley et al. 2015). Moreover, the trade in ornamental orchids exists alongside a trade in medicinal species; even though both involve similar geographies and even some of the same species (e.g., *Dendrobium nobile*), they generally involve separate actors and networks (Phelps 2015). These trades are also largely decoupled from trade in other wildlife (Phelps 2015).

Conservation interventions must thus define which subset of orchid products they target. For example, while conservation actions have primarily focused on overseas markets, much trade is regional (Phelps and Webb 2015). And, although considerable trade occurs at public markets, these are primarily for ornamental species (Phelps 2015); interventions focused on these markets would largely overlook the medicinal trade. Differences among products also shape consumer-facing interventions, and must distinguish between informal gardeners who unintentionally buy wild plants, and specialists who may be aware of, but unconcerned by the conservation implications of their purchases. Although one audience could be targeted with awareness-raising and improved access to sustainable greenhouse-grown plants, specialists might not respond and should perhaps instead be targeted with enforcement.

Example 2: Characterizing actors - South African rhinoceros horn harvesters

South Africa, home to over 80% of the world's remaining white rhino (*Ceratotherium simum*), saw a ten-fold increase in poaching between 2007-2014, principally to supply East Asian medicinal trade (Milliken and Shaw 2012) . Conservation efforts focus on strengthening the enforcement of trade bans, with anti-poaching efforts at the point of harvest, and enhanced enforcement efforts along the supply chain (Biggs et al. 2013; Milliken 2014). Analysis of the actors involved, however, reveals a diversity of harvester types and contexts that may be central to designing more nuanced and effective interventions.

Significant illegal harvest occurs within Kruger National Park by residents of neighboring, generally poor communities, and working for, or with, organized criminal syndicates (e.g., Milliken 2014). However, illegal harvest also occurs on private land: private landholders can collect horns from rhinos that die naturally or are de-horned to minimize poaching risk (Biggs et al. 2013). Horns are stored in guarded vaults, but have recently been subject to theft by organized criminal groups. Faced with this dilemma, some farmers have reportedly colluded to have horns stolen from their property for financial gain, (e.g., SR 2012).

These distinct roles and contexts may merit different interventions. For example, South African landowners can legally own and harvest wildlife on their property. Legalizing international trade of sustainable, non-lethally harvested horn could create incentives for these actors to engage in conservation and sustainable use (Biggs et al. 2013). However, interventions necessarily differ in contexts where wildlife is owned by the state and hunting is illegal, such as in national parks or in Kenya. These contexts may require enforcement alongside alternatives, such as poverty reduction and/or payments to local communities for reduced poaching. However, these responses also require nuance, such as to distinguish among actors responding to local poverty and those involved in outside criminal enterprises (Roe et al 2015).

Example 3: Characterizing actors - Amazonian wild meat consumers

Ecuador's Yasuní Biosphere Park and Reserve is a biodiversity hotspot and home to Waorani indigenous communities, subject to IWT for wild meat. Commercial trade tripled between 2005-2007, dominated by paca (*Cuniculus paca*), collared peccary (*Pecari tajacu*), white-lipped peccary (*Tayassu pecari*) and wolly monkeys (*Lagothrix poeppiggi*) (Suarez et al. 2009). While interventions have traditionally focused on opportunistic enforcement against harvest and transport, analysis highlights the importance of characterizing IWT actors, specifically distinguishing among different consumers.

Local communities have ancestral rights to legally hunt for subsistence consumption (Suarez et al. 2009). This, however, is distinct from the illegal trade to satisfy demand among shift-workers visiting the region (e.g., petroleum industry), rural-to-urban migrants seeking wild meat, and domestic tourists interested in traditional cuisine (Suarez et al. 2009; Poats et al. 2011). This trade expanded in the mid-1990's with increased road access and demand, tripling between 2005-2007 (Suarez et al. 2009).

A collaboration among TRAFFIC, the Ministry of Environment and local communities has tailored interventions to each consumer group (A.Puyol, B.Ortiz, S.V. Poats pers. comms.; Poats 2011). Legal subsistence harvest continues, but has been negotiated with local residents (via incentives, negotiation, enforcement) to promote selective-harvest, a hunting ban in core areas, and reduce commercial IWT. In contrast, low and middle-income urban consumers were targeted with educational messaging to reduce consumption, presented by a popular mayor via the regional bus network. Distinct messaging targeted shift-workers, via the principle regional airline used by industry. The restaurants they frequented were engaged to display signs that they no longer serve wild meat, and were offered cooking training to incentivize their participation. Domestic tourists were targeted through higher-end restaurants and with national television spots.

Example 4: Understanding networks - Indonesian pet reptiles

Indonesia is a leading source in the global trade of pet reptiles, most of which are wild-caught (Fig. 4; Nijman and Shepherd 2009; Lyons and Natusch 2011; Natusch and Lyons 2012). Interventions have traditionally relied on harvest quotas and international trade, although these are poorly designed and/or overlooked (Lyons and Natusch 2011). Trade analysis specifically highlights opportunities for strategic interventions at key points of the network (Fig. 4).

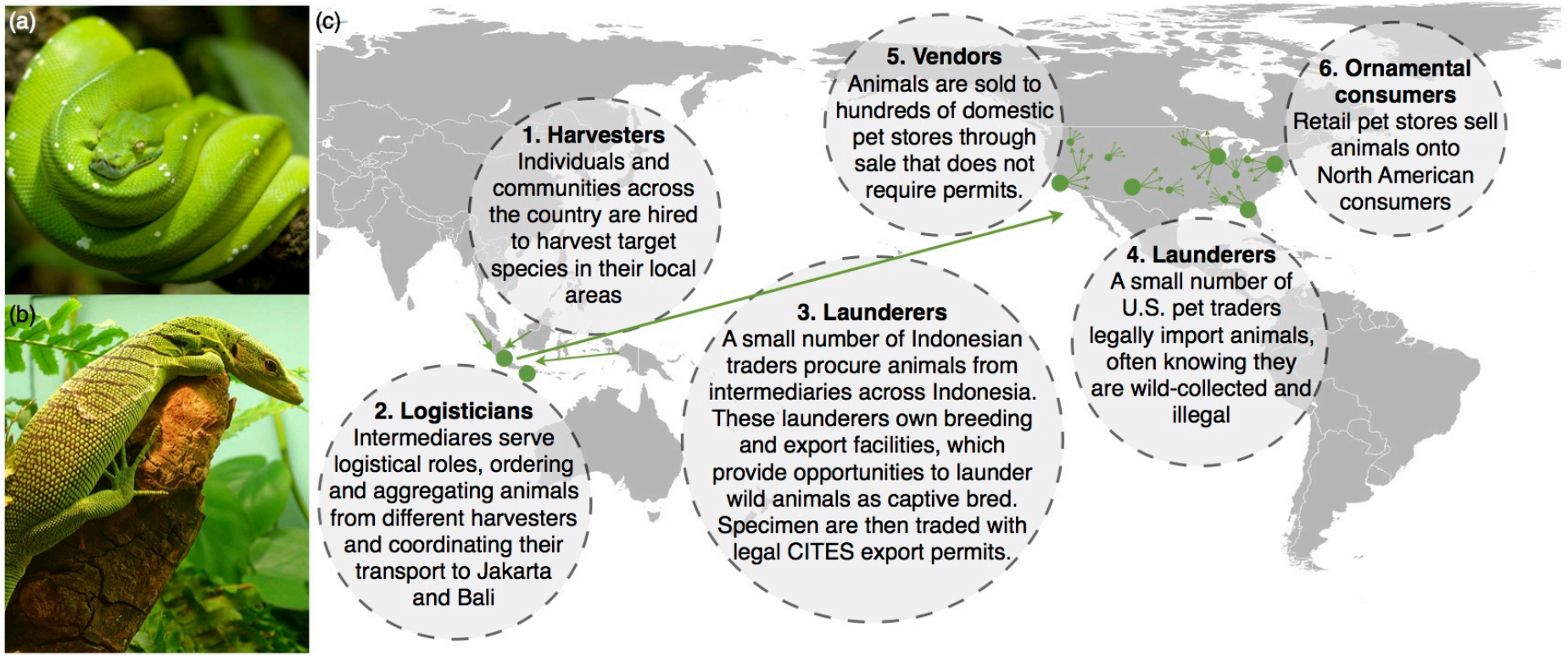


Figure 4. Overview of the illegal trade of wild, protected Indonesian reptiles for the North American exotic pet market. (a) Overview of the illegal trade network and key actor roles (C.Shepherd and S.Stoner pers.comms.; Natusch and Lyons 2012). (b) Emerald tree monitor (*Varanus prasinus*), a species traded as a pet and restricted to New Guinea and adjacent islands (Credit: T.Vickers). (c) Green tree python (*Morellia virdis*), an IUCN Vulnerable species threatened by trade (Credit: S.Niedlich).

The United States is a leading market for wild-collected Indonesian pet reptiles. This trade relies on a small group of gatekeepers (Table 2d), including intermediary logisticians that coordinate harvest across the archipelago, launderers that integrate wild-caught individuals into legal breeding facilities (Lyons and Natusch 2011; Natusch and Lyons 2012), and a small number of US intermediaries (see Table 1). While conservation interventions against the harvesters across hundreds of Indonesian islands would be very challenging and socially detrimental, interventions targeting the US and Indonesian gatekeepers would be relatively efficient and feasible. Their behavior could be shaped through international monitoring and enforcement, and/or new legislation requiring that U.S. importers to obtain proof of parentage to demonstrate animals are indeed captive bred (C.Shepherd and S.Stoner, pers. comms.).

Conclusion

These typologies and the structured analyses they enable can help guide not only conservation actions but also research enquiry. For example, clarification of diverse actor roles that moves beyond caricatures of wildlife poachers will facilitate closer examinations of relative economic benefits from trade, as well as the deeper motivations different actors have for participating in IWT (cf. Duffy et al. 2015), so that these can inform more appropriate, fair and effective conservation actions Similarly, recognition of different types of products and consumers can guide more detailed research on motivations and uses (e.g., Hinsley et al. 2015; Truong et al. 2015).

These typologies can also steer theorizing and testing which types of interventions are most appropriate under different conditions, such as for geographically-restricted versus widely distributed species; species for which consumers are price elastic versus inelastic; and IWT involving local residents versus 'outside' harvesters. Efforts to identify rules of the game are reliant on first identifying terms, and ways to articulate and distinguish amongst actors and phenomena.

The complexity of IWT precludes simple or standardized solutions. Systematic evaluations of IWT products, actors, networks and contexts can play a useful role in guiding future interventions and research. Deeper analyses, informed by these typologies, can inform more strategic, targeted and appropriate interventions for reducing IWT.

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Web Only Material

WebTable 1. Expanded explanation of key parameters discussed in the framework in Figure 3 of the main text.

Key Parameters identified in Fig. 3	Key variables / questions	Description / Examples	Types of implications for ITW	Types of implications for conservation interventions
Contextualize trade	Species biology	• Fecundity • Abundance • Distribution • Seasonality	• Defines product supply, including limits of sustainable harvest and, conversely, taxa vulnerability. • Defines temporally and spatially-explicit accessibility of products • Defines product rarity, price and shapes actor motivations	• Defines when sustainable harvest is compatible with conservation • Informs geographic targeting (e.g., species distribution)
	Physical environment	• Topography • Infrastructure • Seasonality	• Defines accessibility, availability and convenience of harvest • Defines expertise required for harvest	• Directs interventions towards sites and periods of greatest accessibility • Shapes interventions that seek to restrict access (e.g., road planning)
	Social and relational context	• Social networks • Cultural norms	• Defines secrecy of the trade and trust within trade networks • Shapes access to certain sites, technologies and networks • Shapes ability to evade enforcement • Defines the perceived legitimacy of rules on IWT	• Identifies actors that may wield authority or control • Questions the legitimacy of existing rules
	Governance context	• Regulations (local, national, international) • Cultural norms and rules • Enforcement	• Defines probabilities of detection and prosecution that shape cost-benefit analyses • Defines nature and level of sanctions • Defines the perceived legitimacy of rules	• Informs strategies to shift cost-benefits of participating in IWT, such as through increased penalties • Questions the legitimacy of

Key Parameters identified in Fig. 3	Key variables / questions	Description / Examples	Types of implications for ITW	Types of implications for conservation interventions
		• Corruption	on IWT	existing rules
Define products	What is the product?	• Is it the entire organism harvested, or only part (e.g., leaves)? • Are there sub-products associated with one species?	• Defines sustainability of trade • Defines where products originate • Defines where/how they travel • Defines how products are used	• Focuses efforts on the specific product in trade, which could require more nuanced/specialized intervention strategies • Reduces chance of "gaps" in interventions
	How is the product harvested?	• Is the organism killed for harvest? • Does it require specific knowledge technology, or rights?	• Defines sustainability of trade • Defines barriers to participating in trade • Shapes the need for intermediary roles	• Directs interventions that modify harvesting techniques to make them more sustainable (e.g., non-legal harvest). • Directs interventions to actor that play key roles in IWT (e.g., processor)
	What are the legal implications of trade?	• Is there any legal trade? • What rules make the trade illegal?	• Defines the rules of trade across the network and market chain • Defines the legitimacy of IWT rules	• Pinpoints cases of laundering of illegal products into legal trade chains
Characterize actors	What are the key actor roles?	• What types of harvesters, intermediaries and consumers are involved (Table 1)?	• Defines the length and complexity of the market chain, and the barriers to participation in IWT • Defines the types of formal institutions involved in trade (e.g., captive breeding facilities, transportation companies)	• Targets interventions at specific roles in the trade • Defines which official agencies and institutions may/may not be successful conservation partners

Key Parameters identified in Fig. 3	Key variables / questions	Description / Examples	Types of implications for ITW	Types of implications for conservation interventions
			• Defines the involvement of official bodies (e.g., through corruption)	
	Who are the actors?	• Are there key individuals involved in trade? • What are the socio-economic profiles of actors?	• Defines the level of organization and structure of the broader network • Defines how many people are involved • Defines the livelihood reliance on IWT	• Targets interventions at key individuals • Considers the livelihood implications of different interventions on the actors • Defines the accessibility of interventions • Shapes security concerns associated with interventions
	What are the motivations for IWT?	• What are the economics of IWT for trade participants and consumer? • Are there non-economic motivations for participating in trade?	• Shapes actor behaviors, including preferences, price elasticity, risk perception and willingness to change • Defines the types of actors involved, including participation of organized criminal group	• Directs interventions to consider broader incentive/disincentive structures and consider effectiveness of interventions such as alternative livelihoods, changed sanctions, etc. • Identifies strategies to address the non-economic motivations for participating in IWT
Understand networks	How are networks structured?	• What types of harvester, intermediary, consumer configurations are present (Table 2)? • What types of social	• Defines/defined by social relations among IWT actors • Defines profit margins and benefit sharing along market chains • Defines actors' flexibility to participate in trade and to change their behaviors	• Defines strategies to cause the most disruption in a network • Defines accessibility for interventions • Defines how/whether networks are resilient and adaptive to conservation interventions

Key Parameters identified in Fig. 3	Key variables / questions	Description / Examples	Types of implications for ITW	Types of implications for conservation interventions
		relations are reflected in networks?		
	Where are networks located?	• What physical sites are linked by trade • Is trade physical or virtual? • If online, what types of platforms are used (e.g., social media, formal channels, dark web)?	• Shapes relations among IWT actors, including trust, secrecy, concern • Defines the types of technology and access required to participate in trade	• Defines technological demand and knowledge required for interventions to access networks • Potentially involves 3rd parties in restricting trade (e.g., market managers, designers of online platforms)

WebPanel 1. Contextualizing trade: Olive ridley sea turtle eggs

Although the most abundant sea turtle, the olive ridley (Lepidochelys olivacea) was listed as vulnerable in 2008 by the IUCN and is listed on CITES Appendix I; IWT of its eggs is a leading threat (Abreu-Grobois and Plotkin 2008).

Trade analysis highlights harvest as a function of diverse contextual variables (biological, physical, social/relational and governance) that have to be considered in intervention design (Fig. 3). Notably, most olive ridley individuals lay eggs according to individual-specific cues and sites, resulting in low egg availability throughout the year. However, several subpopulations synchronize laying among tens of thousands of individuals, including at Costa Rica's Ostional Beach. This phenomenon is restricted to ~8km of beach over 4 months, which spatially and temporally shapes egg harvest regimes (Madrigal-Ballestero et al. 2013).

Interventions must thus be tailored to these distinct contexts. Indeed, while trade is illegal in most countries and contexts, Ostional uniquely hosts a legal, regulated harvest, restricted to local communities over a limited season. As such, harvest (both legal and illegal) is shaped by governance characteristics, such as association management and rule enforcement. Harvest is also shaped by actor characteristics, such as community membership, actors' economic dependence on trade, livelihood alternatives, and the perceived legitimacy of the existing restrictions (see Madrigal-Ballestero et al. 2013).

Notably, many of these contextual and situational variables are spatially and temporally explicit (e.g., egg abundance, enforcement intensity), leading to distinct situations across space--even for the same species within neighboring communities (Hart et al. 2013).

WebPanel 2. Characterizing actors: Mushroom harvesters in the United Kingdom

The United Kingdom hosts roughly 12,000 species of mushroom, several dozen of which are commonly harvested for consumption (Schulp et al. 2014; FC 2016; FH 2016). Common Law allows legal harvest for personal consumption (defined as 1.5kg per visit), including on others' private land, and with the exception of protected areas (FC 2016). This is contrasted with commercial harvest, which is banned, except with permission of a private land holder (Wildlife and Countryside Act of 1981). However, changes in the actors involved in harvest are increasing pressures on wild mushrooms, and may necessitate changed management.

Recent growth in illegal large-scale, commercial harvest of wild mushrooms, to supply restaurants and markets, linked to growing demand for "wild food", is raising conservation concerns (see Carrington 2014). While the mushroom fruiting can be harvested without removing the whole organism, there is nevertheless concern over over-harvest and its impacts on other organisms (e.g., invertebrates). This has led to small increase in prosecutions of illegal harvesters. (Carrington 2014).

Importantly, there is also concern over a growth collection by subsistence harvesters, especially in high-traffic forests near urban areas and at popular destinations (Carrington 2014). While legal, this practice may be outstripping supply in some areas, and may require changed management that recognizes not only different product uses (commercial versus subsistence), but also different types of subsistence harvesters and the contextual spatial and temporal dimensions of harvest. This approach might shift the parameters of what and where harvest is considered (il)legal.

WebPanel 3. Example of the full use of typology-based framework (see Figure 3): Illegal trade in Southeast Asian ornamental orchids

In the main text, we draw on the example of Southeast Asian orchid IWT to demonstrate the importance of "defining products" in designing conservation interventions. Here we present a full overview of an analysis of the trade in ornamental orchids, which considers the importance of products, actors and networks to shaping conservation interventions.

Southeast Asia's commercial trade in wild orchids involves hundreds of species and several distinct product categories (Phelps 2015; Phelps and Webb 2015). There are, for example, differences between the trade of relatively common ornamental species, and that of rare, expensive species targeted by specialist growers (Phelps 2015; cf Hinsley et al. 2015). Ornamental trade also exists alongside trade in medicinal orchid species; even though both involve similar geographies and species (e.g., Dendrobium nobile) they generally involve separate actors or networks (Phelps 2015). Ornamental trade is also largely decoupled from the trade in greenhouse-grown plants (Phelps et al. 2013) and the trade in most other illegal wildlife (Phelps 2015).

While ornamental trade can involve direct transactions between harvesters and consumers (Table 2b), trade often involves surprisingly diverse actor roles and complex networks (Fig. 2b vs. 2c). Products undergo limited physical transformation, but can involve numerous intermediaries across broad geographies (Fig. 2). Their networks vary in structure, from redundant configurations (Table 2g) to reliance on gatekeepers (Table 2d; Fig. 3). Amidst this complexity, however, open public markets play a disproportionate role (Fig. 2; Table 2f), where trade (species richness, volume) is often dominated by a small number of vendors (Phelps 2013).

To date, conservation interventions are limited, relying on international trade quotas and restrictions. Existing rules, however, are widely disregarded across the region (Phelps and Webb 2015). Elsewhere, isolated interventions have established private and community-based orchid greenhouses, to promote legal sustainable production as an alternative to wild harvest, but have not clearly benefited conservation, and are often geographically distant from the sites of IWT (Phelps et al. 2013).

There is clear scope for strengthened interventions based on improved understanding of IWT dynamics. However, interventions must distinguish among apparently similar, but distinct orchid products. For example, consumer-facing interventions must distinguish between informal gardeners who unintentionally buy wild plants, most likely targeted through awareness raising campaigns and access to greenhouse-grown plants, and interventions targeting specialized collectors that knowingly seek rare species.

Intermediary-facing interventions are also likely to differ. Unknowing 3rd party intermediaries (Table 1) can be targeted through awareness raising and conservation pledges, and potentially with fines for transporting illegal goods. In contrast, targeted criminal enforcement is probably most appropriate against key gatekeepers, such as the minority of traders that dominate market sales at key market and the greenhouses that are laundering wild orchids for international trade (Table 2d; Fig. 3). This would likely be most disruptive to trade, while also limiting social impacts of enforcement.

Even so, many intermediaries are middle-ipncome relative to their neighbors and report having alternative livelihoods (Phelps 2013), such that enforcement-based interventions may have 'acceptable' livelihood impacts (cf. Dickson 2008).

Network mapping also identifies bottlenecks on which to focus interventions. For example, the disproportionate role markets play makes them appropriate and accessible targets (Table 2f). Online trade via public platforms also presents key points for targeted enforcement. Similarly, plants enter Thailand through a limited number of border-crossing where it would be easiest to disrupt trade (Phelps 2015; thesis). In contrast, harvesters are generally geographically very dispersed, and some markets involve many redundant channels. As a result, enforcement or alternative livelihood projects (e.g., community greenhouses) with these groups would likely yield limited conservation outcomes, perhaps except in cases where species are very narrowly distributed (Table 2c).

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