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A Framework for Assessing Supply-Side Wildlife Conservation

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Abstract: *Market-based, supply-side interventions such as domestication, cultivation, and wildlife farming have been proposed as legal substitutes for wild-collected plants and animals in the marketplace. Based on the literature, we devised a list of the conditions under which supply-side interventions may yield positive conservation outcomes. We applied it to the trade of the orchid* Rhynchostylis gigantea*, a protected ornamental plant. We conducted a survey of* R. gigantea *at Jatujak Market in Bangkok, Thailand. Farmed (legal) and wild (illegal, protected) specimens of* R. gigantea *were sold side-by-side at market. These results suggest farmed specimens are not being substituted for wild plants in the marketplace. For any given set of physical plant characteristics (size, condition, flowers), the origin of the plants (wild vs. farmed) did not affect price. For all price classes, farmed plants were of superior quality to wild-collected plants on the basis of most physical variables. These results suggest wild and farmed specimens represent parallel markets and may not be substitutable goods. Our results with* R. gigantea *highlight a range of explanations for why supply-side interventions may lack effectiveness, for example, consumer preferences for wild-collected products and low financial incentives for farming. Our results suggest that market-based conservation strategies may not be effective by themselves and may be best utilized as supplements to regulation and education. This approach represents a broad, multidisciplinary evaluation of supply-side interventions that can be applied to other plant and animal species.*

Keywords: CITES, cultivation, domestication, harvest, nontimber forest products, NTFP, orchid, trade, wildlife farming

Un Marco de Referencia para Evaluar la Oferta de la Conservación de Vida Silvestre

Resumen: *Intervenciones relativas a la oferta, basadas en mercados, como la domesticación y la zoocría han sido propuestas como sustitutos legales en el mercado para plantas y animales recolectadas en su medio. Con base en literatura, diseñamos una lista de condiciones bajos las cuales las intervenciones en la oferta pueden brindar resultados positivos para la conservación. La aplicamos al comercio de la orquídea* Rhynchostylis gigantea*, una planta ornamental protegida. Aplicamos una encuesta de* R. gigantea *en el Mercado Jatujak en Bangkok, Tailandia. Especímenes cultivadoss (legales) y silvestres (ilegales, protegidos) de* R. gigantea *eran vendidos en puestos adyacentes. Este resultado sugiere que especímenes cultivados no son sustituidos por plantas silvestres en el mercado. Para cualquier conjunto de características físicas de las plantas (tamaño, condición, flores), el origen de las plantas (silvestres vs. cultivadas) no afectó al precio. Para todas las clases de precios, las plantas cultivadas tuvieron mayor calidad que las plantas silvestres con base en la mayoría de las variables físicas. Estos resultados sugieren que especímenes silvestres y cultivados representan mercados paralelos y es probable que no sean bienes sustituibles. Nuestros resultados con* R. gigantea *resaltan una gama de explicaciones de la razón por la cual las intervenciones en la oferta pueden carecer de efectividad, por ejemplo, las preferencias de consumidores por productos silvestres e incentivos financieros bajos para el cultivo. Nuestros resultados sugieren que las estrategias de conservación basadas en mercados pueden no ser efectivas por si solas y pueden tener mejor uso como un suplemento para la regulación y educación. Este enfoque representa una evaluación multidisciplinaria de las intervenciones en la oferta que puede ser aplicada a otras especies de plantas y animales.*

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Palabras Clave: CITES, comercio, cosecha, cultivo, domesticación, orquídea, productos forestales no maderables, zoocría

Introduction

Wildlife Trade

Wildlife trade targets a broad range of animal and plant species and their derivatives (CITES 2013). Harvested for a wide variety of medicinal, culinary, aromatic, cosmetic, ornamental, construction, and cultural uses (among others), they are exploited under diverse regimes and intensities. Botanicals, including different nontimber forest products (NTFPs), are especially diverse. Schippmann et al. (2002) calculated that about 50,000 plant species are medicinally exploited and that about 2,500 species are globally traded for medicinal and aromatic properties. However, given the diversity of targeted wildlife species and harvest regimes, the sustainability of wild-collected products varies substantially (Peres 2010).

Sustainable wildlife harvest has been achieved in some contexts, but overharvest is a common outcome of commercialization (e.g., Milner-Gulland & Bennett 2003; Schreckenberg et al. 2006; Warkentin et al. 2009). Overharvest is a prominent threat to the conservation of many plant and animal species (e.g., Sodhi et al. 2004; Warkentin et al. 2009; Sharrock 2011). Overharvest is associated with extirpations and extinctions, cascading ecological effects, and negative economic effects on dependent communities (Peres 2010). Governing wild resources requires nuanced responses, especially given the diversity of exploited species and harvest regimes (Laird et al. 2009). However, wildlife harvest and trade are usually managed through a relatively limited set of conservation policy tools. Policies to ban, restrict, and regulate harvest and trade are most common (Laird et al. 2009), but such policies can require extensive monitoring, enforcement, and resources (e.g., Bulte & Damania 2005; Phelps et al. 2010; Abbot & van Kooten 2011) and can negatively affect rural livelihoods (Dickson 2008). In many contexts, supply-side market-based interventions are more attractive than or are useful supplements to traditional policy instruments (Jepson & Ladle 2005).

Supply-Side Conservation

Supply-side interventions involve domestication and the cultivation, propagation, or breeding of target plant or animal species. Also known as wildlife farming, these interventions are often proposed as substitutes for wild-collected products (e.g., Jepson & Ladle 2005). Theory suggests that flooding the market with legal, high-quality, affordable domesticated products should lessen illegal collection of wild specimens and drive down market prices (Bulte & Damania 2005). Moreover, facing consumer demand and increased rarity of wild resources, harvesters are likely to face incentives to domesticate and farm target species (Homma 1992). Commercialization of domesticated specimens thus has the potential to provide alternatives for conscientious consumers, more reliable and consistent products for industry, and sustainable livelihoods for former harvesters (Larsen & Olsen 2007; Lubbe & Verpoorte 2011) .

Wildlife farming has been implemented for a small, but diverse, group of fauna (e.g., frogs for meat [Warkentin et al. 2009], porcupines for meat [Brooks et al. 2010], bears for traditional Chinese medicine [Dutton et al. 2011]). Similar strategies (cultivation) have been widely promoted as a way to conserve overharvested plant species (e.g., CBD 2001; Schippmann et al. 2002; Flores-Palacios & Valencia-Diaz 2007; Larsen & Olsen 2007; Strandby & Olsen 2008; Sharrock 2011). Wildlife farming may also increase rural livelihood opportunities (Belcher & Schreckenberg 2007; Larsen & Olsen 2007).

Although widely discussed and proposed, "real life examples [of wildlife farming] are scarce and cannot guide decision making;" thus, conservation professionals have often resorted to theoretical and model-based assessments (e.g., Bulte & Damania 2005; Abbot & van Kooten 2011). Even where domesticated specimens are successfully commercialized, it remains uncertain whether they will be substitutes for wild-collected products in the marketplace (Strandby & Olsen 2008; Kirkpatrick & Emerton 2010). Clarifying conditions under which supply-side interventions can yield positive conservation outcomes remains a challenge (Sutherland et al. 2009). Lacking empirical study, supply-side strategies are hotly contested (Bulte & Damania 2005; Brooks et al. 2010; Kirkpatrick & Emerton 2010).

We provide a framework for conceptualizing the factors that shape wildlife harvest and trade through which we developed a list of conditions that shape supply-side interventions and their conservation outcomes. We applied the list of conditions to the Southeast Asian trade in the orchid *Rhynchostylis gigantea*, which has been intensely harvested in the wild and is now farmed commercially. We examined trade of the species at Jatujak Market, Bangkok, Thailand. Both wild-collected (illegal) and farmed (legal) specimens are available in Jatujak Market, so the case provided an opportunity for us to compare wild and farmed products. To our knowledge, this represents one of the first quantitative assessments of whether supply-side intervention has affected a wild-collected product in the marketplace (Brooks et al. 2010).

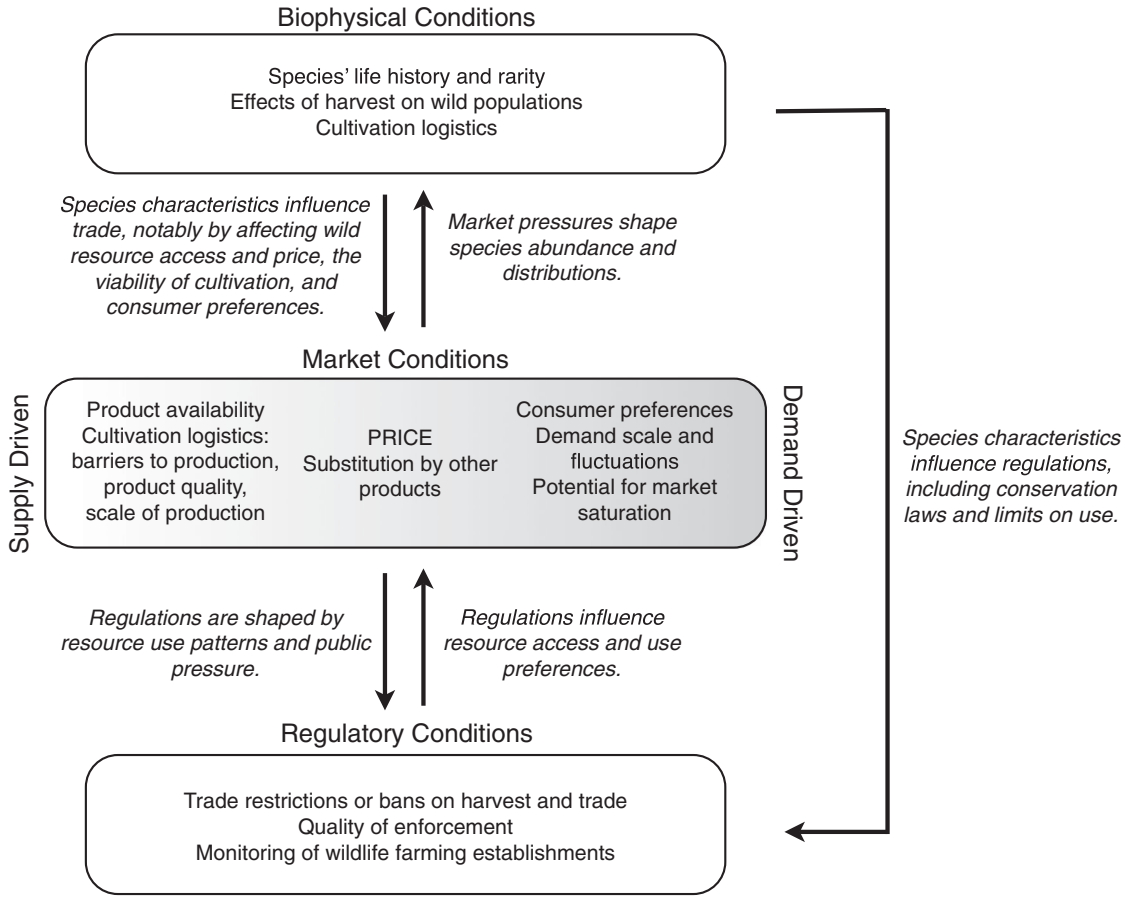

Figure 1. Interactions between biophysical, market, and regulatory factors that shape wildlife trade and farming.

Framework for Conceptualizing Supply-Side Interventions

Harvest, trade, and domestication of wildlife are affected by species' biophysical characteristics, supply and demand pressures, and regulations (Fig. 1). Although economic factors heavily affect which species are farmed (Homma 1992; Larsen & Olsen 2007), other factors also shape supply-side interventions (CBD 2001; Schippmann et al. 2002). For example, a species' life history affects the ease of domestication and commercial production, which are also shaped by marketplace conditions such as consumer preferences. The viability of supply-side conservation strategies thus depends on the interplay of conditions within these 3 categories.

Drawing principally on the NTFP literature, we created a list of the major biophysical, market, and regulatory conditions under which wildlife farming is likely to facilitate the substitution of wild-collected specimens in the marketplace (Table 1). We included existing justifications for why each condition is relevant to determining the conservation outcomes of supply-side interventions, and identified potential analytic tools and resources that can be used to assess each condition.

Methods

We used Table 1 as a guide to our evaluation of trade in *R. gigantea*. We used it to identify to what extent trade in this species at Jatujak Market meets the conditions necessary for supply-side interventions to yield conservation outcomes. We used a subset of the tools and resources identified in Table 1 in a multidisciplinary approach to identify explanations for why farmed plants did not displace wild-collected specimens at Jatujak Market and to identify improvements to supply-side interventions.

Study Site and Species

Jatujak Market (also Chatuchak Market or The Weekend Market) in northern Bangkok, Thailand, is a global center of illegal wildlife trade (Shepherd & Nijman 2008; Todd 2011). Illegal plant harvest to satisfy markets such as Jatujak is a leading threat to Asian botanical diversity and the cause of endangerment for a number of Thai orchid species (Keping Ma et al. 2010). However, trade in wild plants is little regulated and openly practiced (Fig. 2) (e.g., Phelps et al. 2010). Depending on the day and

Table 1. General conditions under which farming is likely to displace wild-collected specimens in the marketplace.[a]

Condition	*Justification*[b]	*Potential analytic tools and resources*
Biophysical conditions		
wild resource generally scarce	rarity means harvest burdens and costs are likely greater, which increases the attractiveness of farming[c,d] price is likely to be higher because of rarity or perceived rarity[c,e]	data on species' abundance and distribution reported conservation assessments[a] collector interviews to assess resource availability[a]
target species subject to destructive harvest	increases the threat of unsustainable harvest, and both depletes the wild resource and increase rarity[f,g]	in situ observations to assess harvest methods collector interviews to assess harvest methods observations of product in market[a]
access to the wild resource uncertain or irregular	farming may provide more reliable access and prove more attractive to market participants[b,i]	market surveys to determine product availability[a] trader interviews to determine product flow[a]
Market conditions		
targeted species of relatively high value	farming needs to be financially attractive[b,j]	market surveys to assess value, including relative to other goods trader interviews to assess value evaluation of whether product is already being farmed[a]
high demand for the target species	market size needs to be large enough to make farming economically viable[f,i,b,k]	consumer and trader interviews to assess demand market chain analysis to assess demand and potential for growth evaluation of whether market already exists for farmed specimens[a]
markets developed and accessible	producers need to be able to readily access customers[f,b,i,k]	market chain analysis to assess demand, potential for growth, market and production locations[a]
demand for the target species reliable and not easily saturated	market fluctuations can limit the financial viability of commercialization and farming[f,b,i,k] market saturation can drive down prices and make farming unattractive[f]	consumer and trader interviews to assess reliability of demand [a] market surveys to assess seasonal trade flows[a]
farmed and wild specimens easily distinguishable in the marketplace	consumers and traders must differentiate among types of products, which may require certification[f,k]	market observations to determine ease of differentiation[a] consumer interviews to ensure ability to differentiate[a]
target species not easily substituted	if consumers accept substitutions (similar species, synthetic substitute) or are unaware a substitution has occurred, then farming may not be financially viable[l,i]	consumer interviews to determine how product is used and to establish consumer preferences[a]
farmed specimens available for the same price or cheaper than wild-collected alternatives	farming needs to be financially competitive with wild harvest; farming can be capital and labor intensive[b,j]	market surveys to determine price differences[a]
farming offers comparable or better profit margins than wild-harvested specimens	farming needs to be financially competitive with wild harvest[d,b]	trader interviews to determine profit margins or perceived differences in profit margins[a]
farmed specimens can be produced at a large scale	substitution depends on farmed specimens being available enough to saturate the market[j]	producer or expert interviews to understand farming logistics market surveys to determine scale of existing production (if any)[a]

continued

Table 1. continued.

Condition	*Justification*[b]	*Potential analytic tools and resources*
quality of farmed specimens good or better than wild-collected specimens	substitution may depend on ensuring that farmed specimens are of comparable quality or potency[f]	measurement of individual characteristics to determine differences between wild and farmed specimens[a] development of qualitative indices through which to assess some characteristics (e.g., physical condition)[a] consumer interviews to assess perceived differences in quality[a]
there is no (or limited) consumer preference for wild specimens	if consumers prefer wild over farmed specimens then these may not be substitutable goods[l]	interviews with consumers of both wild and farmed specimens to determine preferences[a] study of changes in price of wild specimens when cultivated specimens are introduced into the market[a]
few (or reasonable) barriers to farming	lower cost of production helps ensure economic viability of farming[j,n] reduces time to commercialization[i] often includes land-tenure security because farming requires investment and long-term management[f] facilitates broader participation, including potentially by former harvesters greater effort (e.g., for difficult-to-farm species) may be justified for high-value products.	producer or expert interviews to identify extent of barriers field trials to determine viability of farming market surveys to determine whether farmed plants are widely available[a]
Regulatory conditions		
target species subject to harvest or trade restrictions that are well enforced	increases detection and burdens of illegal activity, pushing wild-harvesters out of the market or creating greater incentives for farming; may not be possible in low-governance environments and may create incentives for black-market trade and corruption[o]	review of legislation[a] interviews with key informants (traders, NGOs, government agencies) to assess quality of enforcement long-term market observation[a]
farming establishments adequately monitored	reduces laundering of wild specimens via wildlife farming[p]	review of legislation interviews with key informants (traders, NGOs, government agencies) to assess quality of enforcement

[a]*Tools and resources used to varying degrees in our analyses.*
[b]*References:*
[c]*Homma (1992)*
[d]*Larsen and Olsen (2007)*
[e]*Slone et al. (1997)*
[f]*Belcher and Kusters (2004)*
[g]*Schippmann et al. (2002)*
[b]*Lubbe and Verpoorte (2011)*
[i]*Belcher and Schreckenberg (2007)*
[j]*CBD (2001)*
[k]*Laird et al. (2009)*
[l]*Schreckenberg et al. (2006)*
[m]*Dutton et al. (2011)*
[n]*Bhattacharaya et al. (2008)*
[o]*Abbot and van Kooten (2011)*
[p]*Brooks et al. (2010)*

season, there are approximately 8–31 traders at Jatujak that specialize in wild-collected ornamental plants. Botanical trade at this site provides a unique opportunity to study illegal wildlife trade in detail, although related research remains sensitive and relies heavily on researcher relationships (von Lampe 2012).

Many ornamental plant species are harvested for local and international collectors, including orchid, fern, bromeliad, cacti, palm, cycad, and bulbous plant species (e.g., *Galanthus*) (e.g., Vovides & Iglesias 1994; Robbins 2003; Flores-Palacios & Valencia-Diaz 2007). *R. gigantea* is a charismatic orchid species distributed across Southeast Asia (northeastern India to Vietnam), where it is heavily collected and sold as an ornamental plant (it has no other common uses [Seidenfaden 1988]). Although its conservation status cannot be determined for most of its range (data deficient), the species is considered threatened in Thailand (Santisuk et al. 2006) and is protected by domestic regulations across much of its distribution (e.g., Thailand Forest Act B.E. 1941) and globally under the Convention on the International Trade of Endangered Species of Wild Fauna and Flora Appendix II (CITES 2013). International trade of all wild-collected orchids is regulated under CITES, and orchids represent >70% of CITES-listed species (2013). This is largely because many orchid species are subject to harvest for horticultural markets, are difficult to differentiate, and often occur at relatively low population densities, making them vulnerable to overharvest (Flores-Palacios & Valencia-Diaz 2007). Moreover, as perennial plants subject to whole-plant harvest, species such as *R. gigantea* are especially vulnerable to harvest pressures (Schippmann et al. 2002). Nevertheless, due to lax enforcement in the region (e.g., Phelps et al. 2010), wild-collected plants from Burma, Laos, Cambodia, and Thailand are sold openly to local plant enthusiasts at Jatujak Market, where it known by the Thai name *chang kra*, which refers to the spotted pattern on the flower that resembles freckles on an elephant.

Farming is promoted to support conservation of many orchid species (e.g., Paksong Orchid Project 2011; AOS 2012; Meyers Conservatory 2012; Whrithlington School Orchid Project 2012). *R. gigantea* is commercially propagated (in vitro and from seed) and has been sold at markets across Thailand for over 10 years. In addition to specimens with wild-type flowers, which is the color pattern most commonly found in the wild, greenhouse farmed specimens are also available with variegated, white, red, and peach flowers (Supporting Information).

Market Survey

As part of a broader survey of wild plant stalls at Jatujak Market, we recorded all wild *R. gigantea* in the marketplace during monthly surveys that ran from 1 June 2011 to 23 May 2012. During the 2012 blooming season (late January to mid-February), we surveyed all stalls selling

Figure 2. Stall specialized in selling wild-collected ornamental orchids at Jatujak Market, Thailand (February 2012).

propagated ($n = 17$) and wild-collected ($n = 8$) *R. gigantea* (during other times of the year wild and farmed plants are sold without flowers). Wild and farmed orchids can be easily distinguished by their physical condition on the basis of criteria identified by Kew Botanic Gardens and the CITES Secretariat for training customs agents (e.g., root and insect damage, cracking, and dehydration) (McGough et al. 2004; GreenCustoms 2012) (Supporting Information).

We sampled (measured without purchasing) all wild-collected *R. gigantea* ($n = 401$) and all propagated plants with wild-type flowers ($n = 128$). For horticultural varieties (peach, white, red, variegated flowers), we delineated price categories of 50 Thai Baht (THB) (approximately US$1.60) and sampled 50% of specimens in each price category ($n = 341$). We recorded the trader-reported price for each farmed individual. Because most wild plants were sold by weight, we calculated prices by weight of each individual. For each individual, we recorded type of growing container, number of leaves, length of longest leaf, and length of longest live root as proxies of plant size. We could not weigh farmed plants because some were grown in receptacles

Table 2. Comparison of farmed versus wild *Rhynchostylis gigantea* in bottom- and top-price classes for 7 physical characteristics (see also Supporting Information).

		Farmed			*Wild*			
*Price class**	*Plant character*	*n*	*mean (SD)*	*median*	*n*	*mean (SD)*	*median*	*Independent samples t or Mann Whitney test*
≤50		85			210			
	longest leaf		8.5 (2.1)			18.4 (7.0)		$t(277) = 18.7$, $P < 0.001$
	longest root		6.3 (4.0)			5.1 (4.0)		$t(293) = -2.38$, $P = 0.018$
	number leaves			5			4	$U = 312350$, $Z = -8.99$, $P < 0.001$
	number of inflorescences			0			0	$U = 8172.50$, $Z = -1.43$, $P = 0.152$
	flower condition						1	-
	plant condition			6			3	$U = 242.50$, $Z = -13.44$, $P < 0.001$
	number of additional shoots			0			0	$U = 8920.00$, $Z < 0.001$, $P = 1.00$
>200		122			32			
	longest leaf		23.5 (4.2)			30.4 (6.5)		$t(38) = 5.72$, $P < 0.001$
	longest root		51.5 (22.1)			18.6 (12.8)		$t(81) = -10.77$, $P < 0.001$
	number leaves			7			8	$U = 1658.50$, $Z = -1.26$, $P = 0.208$
	number of inflorescences			2			0	$U = 780.00$, $Z = -5.55$, $P < 0.001$
	flower condition			3			1	$U = 244.00$, $Z = -9.82$, $P < 0.001$
	plant condition			6			4	$U = 114.50$, $Z = -9.48$, $P < 0.001$
	number of additional shoots			0			0	$U = 1489.00$, $Z = -4.83$, $p < 0.001$

Divided into THB50 price classes (approximately US$1.60).

of different weights. For plants in bloom, we recorded the number of inflorescences and flower color. For wild plants, we recorded country of origin as reported by the traders. We photographed each individual orchid, from which we developed an index to assess plant and flower condition (Supporting Information). Scoring did not include the number and spacing of flowers, differences in flower shape and size, or plant compactness or symmetry, characteristics that may have affected some (specialist) buyer decisions. However, few wild plants were observed in bloom during the study (<10%); thus, flower details may be less important than other physical characteristics.

Consumer and Vendor Interviews

We interviewed all willing wild plant traders ($n = 7$, 87.5% of the wild-plant trader stalls). Respondents were all Thai females, and 2 (28.6%) of them were of retirement age (over 60 years old). The rest of the traders were of working age. We interviewed all willing farmed-plant traders ($n = 6$, 35% of all farmed plant stalls). Three respondents were Thai females and all respondents were of working age.

During interviews we asked about plant origins; whether they perceived customers had specific preferences for farmed or wild plants. For wild-plant traders, we asked why they sold wild plants instead of farmed plants. Sensitive information provided by the wild-plant traders was generally considered reliable because respondents were forthcoming and knew the lead researcher, who had made >60 market visits and had previously conducted interviews with the traders. A relationship-based approach to interviews can increase respondent candor about sensitive subjects (Burns & Miggelbrink 2011).

We conducted opportunistic interviews with consumers in the marketplace who purchased wild plants ($n = 8$, 3 Thai females, 3 of retirement age) and farmed plants ($n = 15$, 9 Thai females, 3 of retirement age). The purpose of interviews was to determine whether buyers could distinguish between wild and farmed plants; identify types of plant selection criteria; and determine whether they showed any preferences for wild plants. We positioned ourselves at plant stalls throughout the market and approached buyers observed purchasing the target species. We avoided double-counting by taking notes on each consumer and confirming that they had not been interviewed previously.

Both trader and consumer interviews were limited by sample size. Trader interviews were limited by the total number of potential respondents (only 8 traders in the market sold wild *R. gigantea*) and the number of willing respondents. Consumer interviews were limited by several factors: the short blooming season of *R. gigantea*, buyers and stalls were scattered across a large market, and requests by several traders (>5) that we not disturb their customers. As a result of these limitations, we used interview data principally as supplementary information. We identified common perceptions and themes, rather than assessing demand, identifying correlations,

or measuring differences among groups. Similar themes recurred during successive interviews. In these types of cases, even very small nonprobabalistic sample sizes (e.g., 6 respondents) can provide reliable data for qualitative analyses (Guest et al. 2006).

Analyses

We divided the data set price categories into increments of 50 Thai Baht (THB50, THB100, etc.) (THB50 is approximately US$1.60). Although prices differed among traders, plants were generally priced in increments of THB50. We used independent samples *t* tests and Mann-Whitney tests to determine whether there were significant differences between farmed and wild plants for each physical characteristic in each price category. We used a mixed-effects generalized linear model (GLMM) (Pinheiro & Bates 2000), with trader as a random effect, to determine whether plant origin (wild vs. farmed) was a reliable predictor of plant price after controlling for the measured physical characteristics. We performed analyses for the entire data set, including all flower colors. Wild-collected plants were usually only available with wild-type flowers, so we repeated this analysis with plants with only wild-type flowers.

Results

Plant Supply

R. gigantea is subject to year-round trade at Jatujak Market, although volume fluctuated through the year (Supporting Information). Over 2000 wild plants were observed during the broader 2011–2012 survey period, which represents a conservative estimate because surveys were monthly and overlooked wholesale transactions and informal transactions outside of market days. Traders reported country of origin for approximately 70% of plants, most of which originated from Thailand (26%) and Laos (33%) (Supporting Information).

Wild plants were traded throughout the year, peaking during the blooming season. Farmed plants were principally traded during the blooming season (Supporting Information). Although farmed specimens were present in the marketplace during other times of the year, their numbers were low and traders confirmed that farmed plant sales were strongly skewed toward the blooming season.

During the February 2012 survey, traders sold 728 farmed plants and 401 wild-collected plants. Of these, 17 traders sold only farmed plants, 7 traders sold only wild plants, and 2 traders sold both types of plants.

Wild-collected *R. gigantea* were generally sold by the kilogram. Plants were sold for THB350–450/kg (approximately US$11.60–15.00/kg), depending on plant size. Despite changes in the trade volume of both wild and farmed plants throughout the year, the price of wild plants did not change throughout the year, which was also confirmed by the traders. Notably, the price of wild plants did not change when farmed plants flooded the marketplace during the blooming season.

Table 3. Variables significant in determining price of *R. gigantea* for all with wild type flowers (blooming and nonblooming specimens).

Variable	*Estimate*	*SE*	*z*	*Pr(>|z|)*
Intercept	1.41	0.15	9.30	< 2e-16
Origin (wild)	0.72	0.62	1.15	0.25
Length of longest leaf	0.06	0.00	46.76	< 2e-16
Length of longest live root	0.01	0.00	43.53	< 2e-16
Number of leaves	0.14	0.00	38.94	< 2e-16
Number of inflorescences	0.15	0.01	19.36	< 2e-16
Plant condition score	0.14	0.01	24.04	< 2e-16
Bare-root or no receptacle	0.58	0.05	10.84	< 2e-16

Plant Characteristics

Farmed plants differed significantly from wild plants for most physical characteristics (Table 2 & Supporting Information). Wild plants had longer leaves than farmed plants. In each price category, farmed plants had more leaves, had longer roots, were in better physical condition, had more inflorescences, and had flowers that were in better condition (Table 2). Thirteen percent of wild plants were in bloom, 3.7% were planted into pots or baskets (the rest had bare roots). Eighty-two percent of farmed plants were in bloom, and 100% were planted in pots or baskets (Supporting Information).

GLMM

The GLMM showed that although plant origin (wild vs. farmed) was a predictor of plant price, it was among the least influential of the categorical variables we considered, positively affecting price by THB0.54 (US$0.02) (Table 3). Most other recorded categorical variables were also significant in influencing plant price (Table 3 & Supporting Information). Notably, the variety and flower color of cultivated plant influenced price by anywhere from THB0.65 to 5.9 (approximately US$0.02–0.20). How the plants were grown was also a leading determiner of price. Plants that were grown on a piece of wood and plants that were not grown in a plastic receptacle increased price by approximately THB2 (approximately US$0.07). Of the continuous variables assessed, longest leaf and root length most affected plant price, increasing price by THB1 (approximately US$0.03)/cm length (Supporting Information).

Because wild-collected plants were generally only available with wild-type flowers, the data were partitioned by flower color. When only plants with wild-type flowers were considered, plant origin did not explain plant price (Table 3). However, a number of physical characteristics remained predictors of plant price, including leaf and root length, number of leaves and inflorescences, plant condition, and whether the plant had been potted, all of which affected price by approximately THB1–2 (Table 3). This result indicated wild-origin was not the cause of the price difference between wild and cultivated plants in the first analysis, but rather that price was principally linked to flower color.

Interviews

All 23 interviewed consumers knew the Thai species name of the plant they had purchased, and all but one could distinguish between wild and farmed plants. Eleven consumers stated exclusive preference for cultivated plants, 4 stated a preference for wild plants, and 8 stated no preference for either cultivated or wild plants. Respondents provided diverse justifications to support their preferences for wild plants, including that they were considered more fragrant, stronger, and easier to grow (Supporting Information). Preferences for cultivated plants were principally related to the flowers, which were available in a broader range of colors and often considered more attractive. Five respondents reported preferring cultivated plants because they were better for conservation, although this reply may have been biased by respondents seeking to please the interviewers (Supporting Information).

Traders ($n = 13$) confirmed seasonality of farmed *R. gigantea* and that they were generally able to sell all or most of their stock. Three of the 6 interviewed farmed plant traders reported purchasing plants from commercial greenhouses, and 3 reported growing plants themselves (although seedlings may have been purchased from commercial greenhouses).

Wild-plant traders reported that plants were usually ordered from middlemen who bought the plants from other middlemen, traders, and harvesters across the region. No wild-plant trader thought there was a difference in profit between wild and farmed plants sales; none considered relative profit margins a factor in their decision to sell wild plants. Five of the wild-plant traders explained their decision to trade wild plants as a matter of personal and consumer preferences for wild over farmed plants (Supporting Information). Two traders also identified the high cost of purchasing farmed plant stock as a barrier that restricted them to wild sales.

Both traders of wild and farmed plants described their customers as a combination of members of the general public and hobbyists with specialist knowledge. Vendor reports of consumer preferences for wild versus farmed plants were consistent with the reasons stated by consumers themselves (Supporting Information). Traders of wild plants further reported that the supply of *R. gigantea* plants and other species were greatest when flowering, but were variable across seasons and also from week to week, presumably affected by collector ability to find wild stock, which is also a documented challenge of commercializing NTFPs (Belcher & Schreckenberg 2007).

Discussion

Although affordable and high-quality propagated *R. gigantea* orchids were widely available, illegal wild specimens remained common in trade. Although farming may have already reduced demand for wild specimens from an undocumented historical high, farmed plants were not a complete substitute for wild plants in this marketplace. Persistence of wild-collected specimens could not be attributed to differences in price. Farmed plants were priced comparably to wild-collected plants and were physically superior to wild plants for almost every character. Several noneconomic factors may have limited the conservation outcomes of farming. We reviewed the evidence on *R. gigantea* relative to conditions in Table 1 to determine possible reasons the supply-side intervention was not fully effective in displacing wild-collected specimens (Table 4).

Limited by historical and biological data, time, and resources, we used only some of the proposed analytic tools and resources (Table 1). Moreover, we focused on market-based actors and did not examine the entire market chain, which would be necessary to fully understand harvester motivations and barriers to their participation in farming. Where possible, we used multiple lines of evidence to determine whether a condition was met and where evidence was based on a limited data set, we considered the condition uncertain (Table 4).

R. gigantea met most of the conditions for successful commercialization of a farmed plant species, including conditions related to the economic viability of farming. Farmed specimens were available for the same price as wild-collected specimens. This contrasts with many wild-collected products, which are often less expensive than their farmed alternatives (Belcher & Schreckenberg 2007; Lubbe & Verpoorte 2011) or attract a price premium where there are widespread preferences for wild origin (e.g., Dutton et al. 2011). If consumers were to seek the largest, healthiest plant in bloom for any given price category, our results suggest they would consistently choose farmed over wild-collected plants. Although some consumers may prefer smaller ornamental plants, on the basis of selection-criteria identified during the interviews ($n = 23$) and our longer-term (2 year) observations at Jatujak Market, we noted that consumers tended to prioritize plant size and health, both of which were greater

Table 4. Assessment of *R. gigantea* relative to the conditions identified in Table 1.

Condition from Table 1	*Condition met for R. gigantea?*	*Evidence collected for R. gigeantea*
Wild resource is generally scarce	yes	traders reported supply is erratic, presumably because plants are sometimes difficult to find in the wild
		species listed as "threatened" in Thailand
Species subject to destructive harvest	yes	species were subject to whole-plant harvest
Access to wild resource is uncertain or irregular	yes	monthly surveys revealed large variability in market volumes
		traders reported inconsistent supply of wild plants
Targeted species is of relatively high value	yes	species were already subject to large-scale farming, which suggested it was of high enough value to be attractive for commercialization
High demand for the target species	yes	presence of farmed plants at the market implied adequate demand to have spurred farming
Markets developed and accessible	yes	plants were farmed in large-scale greenhouses, most near Bangkok
		Jatujak plant market was well established and many plant traders sold cultivated *R. gigantea* there
		market for wild orchids may have been more specialized than the market for farmed plants
Demand for target species reliable and not easily saturated	no or uncertain	demand for farmed plants was highest during the blooming season (~1 month), as confirmed by vendors and evident because plant volumes were much smaller during other times of the year
		sales of wild plants peaked during the blooming season, but plants were available year-round
		lack of data on demand
Farmed and wild specimens easily distinguishable in the marketplace	yes	the 2 categories of plants were be easily distinguished
Target species not easily substituted	uncertain	many other orchid species, hybrids, and other flowering plants were available in the market place, which may be substituted for *R. gigantea*
		R. gigantea was well known in Thailand; all consumers interviewed knew the name of the orchid they had purchased and may have been specifically sought this species
Farmed specimens available for the same price or cheaper than wild-collected alternatives	yes	generalized linear model (GLMM) showed that after all physical variables had been controlled for, there was no difference in price between wild and farmed plants
Farming offers comparable or better profit margins than wild-harvested specimens	yes or uncertain	wild-plant traders reported that they did not think there was a different in profit margins between wild and farmed plant sales; did not emerge as a major factor in decision to sell wild plants
		from GLMM results, farmed plants not commanding a premium and may not present a financial incentive for wild-product traders to transition to farming
Farmed plants can be produced at a large scale	yes or uncertain	during the blooming season, farmed plants outnumbered wild plants in the marketplace
		farmed plants only seasonally available in large quantities in the marketplace

continued

Table 4. continued.

Condition from Table 1	*Condition met for R. gigantea?*	*Evidence collected for R. gigeantea*
Quality of farmed specimens is good or better than wild-harvested specimens	yes or uncertain	univariate tests showed that for each price category, farmed plants were generally of superior quality to wild-collected plants some consumers perceived differences in flower quality and fragrance and in the "authenticity" of cultivated plants
No (or limited) consumer preference for wild specimens	no	price of wild plants does not respond to the introduction of farmed plants during the blooming season, suggesting they are distinct commodities half of interviewed consumers who purchase wild plants expressed a clear preference for wild plants traders who sell farmed plants were not the same traders in wild plants, suggesting that these are separate goods
Few (or reasonable) barriers to farming	yes or uncertain	species was commonly farmed and sold in Thailand, which suggests limited barriers most traders of farmed plants purchased stock from large wholesale greenhouses, suggesting a production barrier exists for small traders plant harvesters (although beyond the scope of the study) were very unlikely to be able to participating in commercial growing cost of purchasing initial wild orchid stock probably lower than purchasing farmed plants
Target species subject to harvest or trade restrictions that are relatively well enforced	no	although illegal, wild plants openly sold at the market; enforcement was weak and erratic
Farming establishments adequately monitored	no or uncertain	as most farmed plants are horticultural varieties (distinguished by their flowers), laundering is not likely a major issue for this species at this market. However, greenhouses are not regularly monitored.

among farmed plants. Yet, wild-collected plants remained common in trade.

Other explanations for this phenomenon include the possibility that wild and farmed plants were non-substitutable goods that represented parallel markets (Table 4), as has been noted for some other wildlife products (e.g., Himalayan medicinal plants [Larsen & Olsen 2007], Christmas trees [Strandby & Olsen 2008], bear bile [Dutton et al. 2011]). First, the price of wild plants did not change when farmed plants flooded the marketplace; the price of substitutable goods would have likely changed with the influx of a competing product (Bulte & Damania 2005). Second, some buyers showed specific preferences for wild plants. The presence of farmed specimens in the marketplace would have little effect on these buyers' decisions. Third, all but 2 traders specialized in either wild or farmed plants, suggesting a division between products. Moreover, wild-plant traders expressed a personal preference for selling wild plants. This factor was not considered in our framework but supports the separate-market conclusion. This separation was probably the result of not only vendor and consumer preferences, but also of trader networks and differences in capital demands between wild and farmed plants.

It is possible that barriers to farming limited some vendors' transition to farmed plants, although this could not be fully assessed with the available data (Table 4). *R. gigantea* is widely farmed by large commercial greenhouses, from which some farmed plant vendors purchased seedlings or mature plants for resale. However, there are likely barriers to participating in plant cultivation by individuals because orchid farming requires specialized knowledge and a substantial capital investment. In addition, some traders indicated the costs of buying plants from greenhouses may be higher than buying plants collected in the wild. The barriers to cultivation may also be great for plant harvesters, particularly if they these are poor or live in isolated forest regions.

Another factor that could explain the persistence of wild plants in the marketplace is that farmed plants were only widely sold during the short blooming season; traders also reported that sales were seasonal (Table 4). In contrast, wild plants were rarely traded in bloom (even in the blooming season flowers were heavily damaged or removed), so sale prices and consumer motivations for buying wild plants may be less influenced by seasonality. The seasonal flooding of the market with farmed plants may be inadequate to force a substitution. Moreover, it seems likely that farmed specimens were traded largely for their flowers, whereas wild specimens were traded based on characteristics other than their flowers.

The lack of regional enforcement of wildlife harvest and trade regulations (Shepherd & Nijman 2008; Phelps et al. 2010; Todd 2011) may also have contributed to the substitution failure (Peres 2010) (Table 4). Traders faced few disincentives to selling wild-harvested protected plants. As they reported personal preferences for wild plants and did not perceive differences in profit margins between wild and farmed plants, those traders may have had few incentives to transition to selling farmed plants.

Improving Supply-Side Interventions

Results of our approach can guide more critical evaluations of supply-side interventions to assess species' suitability for wildlife farming, anticipate potential shortcomings, and identify additional interventions needed to strengthen conservation outcomes. Similar analyses could be implemented for other species at Jatujak Market, including trade in the genera *Nepenthes, Adiantum, Platycerium, Asplenium, Cycas, Aerides, Dendrobium, Ascocentrum,* and *Vanda* and the CITES Appendix I-listed genus *Paphiopedilum*. The approach could also be applied to threatened animal species to inform associated debates, such as recent proposals to allow tiger farming to produce traditional Chinese medicines (Kirkpatrick & Emerton 2010).

Our observations on *R. gigantea* are especially relevant to species for which consumers prefer wild-collected specimens, including some medicinal products such as tiger parts and rhinoceros horn; luxury wildlife products such as ornamental plants and caviar; bluefin tuna (*Thunnus thynnus*); some bushmeat; and collectible wildlife such as butterflies, beetles, and exotic pets (e.g., Gault et al. 2008; Dutton et al. 2011; Tournant et al. 2012). The problem is compounded by consumer preferences for rare species, which drive trade, increase rarity, and promote further demand (Courchamp et al. 2006). However, as highlighted by our example, neither product price nor consumer preferences necessarily fully explain supply-side dynamics; seasonality, participation barriers, and trade scale may also have substantial effects.

Our framework and case study further highlight where additional interventions may facilitate conservation; supply-side interventions may not present perfect self-regulating market solutions (Abbott & van Kooten 2011). On the contrary, interventions to curb wildlife trade generally require both a holistic approach and a mixture of policies (Laird et al. 2009; Abbot & van Kooten 2011). Complementary interventions for *R. gigantea* might include consumer and vendor education about botanical conservation and regulations; technical and microcredit assistance for wild-plant vendors and harvesters to gain access to new technologies or farmed plant trade networks; basic ecological research on *R. gigantea*; and tracking of wild-plant sale volumes and origins to determine scale of trade. Conservation outcomes may further depend on accompanying supply-side interventions with unambiguous disincentives for wild-product trade that require clear regulations and increased enforcement at points of harvest, import, and sale.

Yet, increased enforcement aimed at harvesters of wild products can be contentious (Dickson 2008), costly, and challenging in low-governance environments (Peres 2010; Abbot & van Kooten 2011).

Although the economic logic and theoretical underpinnings of supply-side interventions may be robust, there remain logistical challenges to addressing socioecological problems involving international market chains. The design and evaluation of supply-side interventions is complex in practice and limited by substantial knowledge gaps. There is a need for expanded and creative approaches to gathering and evaluating multiple lines of evidence—not only about the technical viability of cultivation or farming, but also about consumer preferences, consumer ability to distinguish among products, and differences in quality and characteristics between cultivated and wild specimens. Our framework and the conditions in Table 1 provide a starting point for integrating these data to feed into a broader, more multidisciplinary enquiry of supply-side interventions. They can they be applied to other species and further developed to help identify whether interventions will yield conservation outcomes.

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Supporting Information

Main color patterns of farmed *R. gigantea* and comparison of wild and farmed plants in the marketplace (Appendix S1), common signs of wild harvest (Appendix S2), market volume of *R. gigantea* (Appendix S3), trader-reported country of origin for wild-collected *R. gigantea* (Appendix S4), comparison of cultivated versus wild plants by price class for 7 physical characteristics (Appendix S5), *R. gigantea* descriptive statistics (Appendix S6), results of GLMM showing the factors affecting price of *R. gigantea* (Appendix S7), and frequency of reported justifications for cultivated or wild plant preferences (Appendix S8) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding authors.

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