Chapter 11
A Conceptual Framework for the Management of a Highly Valued Invasive Tree in the Galapagos Islands

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Introduction

The increasing movement of people and goods across the globe has allowed numerous organisms to jump natural dispersal barriers and become introduced to new sites (Work et al. 2005). In some cases, they become established, rapidly expand their populations, and become extremely noxious, causing significant ecological impacts and economic harm (Mack et al. 2000; Pimentel et al. 2000). Ecological impacts from introduced species can include significant changes in ecosystems services (Hobbs et al. 2013), and these and other impacts are extensively reviewed in other chapters of this book.

This group of ecologically and economically harmful organisms—"invasive species" (sensu Richardson et al. 2000)—represents approximately 10% of all new non-native plant introductions (Williamson and Fitter 1996). For certain invasive species, for example, those expected to cause large damages and/or those that have not yet extended their range significantly, eradication may be optimal (Simberloff 2008).

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Though rarely, in highly unique cases, eradication has been achieved (Gardener et al. 2010, 2013), including *Rubus* species in Santiago Island, Galapagos (Renteria et al. 2012), and zebra mussels in a small pond in the continental USA (Adams and Lee 2011). Efforts to eliminate invasive species have helped us understand factors that affect eradication success, which can include intrinsic ecological characteristics of the target species, such as fast growth and high offspring, insufficient budget, related logistic constraints, and social attachment by settlers (i.e., seen as beneficial or harmful; e.g., Cruz et al. 2009; Simberloff 2003).

In addition to the fairly well-described ecological impacts caused by invasive species (Daehler 2003), recent studies have focused particularly on analyzing the social impacts and related costs these introduced organisms can generate (Liu et al. 2011). For instance, there are reductions in boating and fishing caused by colonization of Eurasian watermilfoil (*Myriophyllum spicatum*) and decreased recreation (i.e., park use) due to the tree *Melaleuca quinquenervia* in the USA (Charles and Dukes 2008). These examples illustrate how invasive species can negatively impact socioeconomic values. Understanding the critical role that the broader social system plays in invasive species management may improve management effectiveness and perceived success (García-Llorente et al. 2008; Gardener et al. 2010; Kholi et al. 2008; Epanchin-Niell et al. 2010; Larson et al. 2011; Kalnicky et al. 2014; Rai and Scarborough 2014).

Despite the many examples of negative ecological, social, and economic impacts from invasive species, their management may not be beneficial for all affected stakeholders. Some invasive species clearly cause great harm and are not generally viewed as beneficial (e.g., fire ants—*Solenopsis invicta*), mainly because they were unintentionally introduced and cause significant negative damage to livestock and humans (Pimentel et al. 2001). However, a subset of invasive species was intentionally introduced for perceived social and economic benefits, and these were only later identified as invasive once their ecological effects became apparent (Kennedy and Hobbie 2004). Three notable examples include salt cedar (*Tamarix* spp.), introduced to control erosion, *M. quinquenervia* to dry up the Everglades, and kudzu (*Pueraria lobata*) for erosion control and livestock forage (Di Tomaso 1998; Webster et al. 2006). For these, and other species, there can be much less motivation to eradicate or actively manage invasions given positive public perceptions (Moyle 2001; Colautti and MacIsaac 2004; Webster et al. 2006; Pejchar and Mooney 2009; Adams et al. 2011; Davis et al. 2011).

Perceived benefits can complicate invasive species' control and management and frustrate policy interventions if diverse stakeholders have opposing views about their positive or negative impacts (Schlaepfer et al. 2011). For example, the negative effects that *Pinus* species can cause to the native ecosystems they invade are well known (Richardson and van Wilgen 2004), but in some regions (e.g., South Africa), they are highly valued for timber and non-timber forest products that support local residents (de Wit et al. 2001). While removing these trees may positively affect stream flow (Richardson and van Wilgen 2004) and diminish their ecological impact, it might result in significant economic losses to those using the trees (Turpie et al. 2003), who might oppose the control and reduction of this species.

These examples highlight the importance of understanding the social landscape in which invasive species exist, including identifying stakeholders and defining their roles and perhaps, critically, identifying which groups would view invasive species removal as beneficial or detrimental. Recent literature on social conflicts and invasive species management recognizes the need to explicitly include both ecological and socioeconomic aspects of invasive species assessments, identify impacts on diverse stakeholders, and consider policy mechanisms (e.g., incentive payments) that address their concerns (Estévez et al. 2015).

Despite a recognized need for management programs that incorporate mechanisms to reduce the negative ecological, economic, and social impacts of invasive species (e.g., Adams and Lee 2012), we often lack sufficient information to guide policy and management decisions about new invasions (e.g., Leung et al. 2002) or to understand impacts that such management projects may have on different stakeholders. However, researchers have used a variety of methods to inform these decisions despite the inherent uncertainty associated with new and potential invasions, i.e., bioeconomic modeling (e.g., Adams and Lee 2012). Such investigations are useful for gauging socioeconomic impacts and simulating the effects of potential invasive species management approaches (e.g., Lee et al. 2009; Adams et al. 2011; Adams and Lee 2012). What is most clear from these, and related studies, is that identifying the appropriate management approach requires a strong understanding of the target species' effects and impacts—ecological and otherwise. The identified negative and positive impacts can be later included in managerial decision-making that may help to reduce the risk of failure of restoration projects (Rai and Scarborough 2014).

Conceptually, this can be done using a coupled human-natural systems approach that incorporates observations on both the ecological and social systems and their interactions (Liu et al. 2007). However, in practice, this is rarely done (Pejchar and Mooney 2009; Estévez et al. 2015). Notable exceptions include analyses of the social dynamics surrounding an invasive species introduction by conceptually "mapping" local stakeholders being impacted (positively or negatively), describing the relationship among stakeholders, and analyzing the expected impacts of management alternatives on stakeholders groups (e.g., Leung et al. 2002; Richardson et al. 2009). This is a critical area of inquiry that has received insufficient attention in the scientific literature.

Here, we use descriptive analysis and survey and interview methods to understand the case of the invasive and economically important tree *Cedrela odorata* in the Galapagos Islands, Ecuador, where the tree is viewed as both beneficial and harmful to stakeholders; explore the complex social, economic, and ecological aspects of invasive species management; and identify the stakeholders that could be impacted by potential managerial actions targeting this invasive tree.

Despite the significant ecological impacts of *Cedrela* in Galapagos (see chapter by Rivas-Torres and Rivas) and its economic importance for the local timber market (Methods section), no studies have assessed the socio-environmental dynamics of *Cedrela* or the impacts of alternative *Cedrela* management approaches (e.g., *Cedrela* eradication and site restoration) on stakeholders. In the following sections, we summarize the ecological impacts of *Cedrela* to assess its biotic effects and describe

the stakeholder groups engaged on this issue, including governmental agencies, local residents, and timber workers. Next, we explore the costs and benefits to stakeholder groups associated with *Cedrela* management and forest restoration and the loss of the tree as a key commodity. Finally, we present a conceptual model of the socioecological landscape that could inform *Cedrela* management by the GNP. Using this model, we compare two competing policy alternatives that are being considered for adoption: (1) continued use of *Cedrela* for the local wood products market and (2) complete extraction and eradication of *Cedrela* within the GNP (GNP Directorate 2014). Besides adding to the small but important literature on the socioecological impacts of invasive species management, this chapter also fills critical knowledge gaps about *Cedrela* impacts and alternative management approaches. Results of this study also have practical importance for the management of invasive species in the Galapagos Islands.

Methods

Background and Target Species

In the 1940s, the invasive tree *Cedrela odorata* (Meliaceae; hereafter *Cedrela*) was introduced to the farms located in the highlands of Santa Cruz Island (at the center of the Galapagos archipelago; Lundh 2006) and today is also found on the other three inhabited Galapagos islands (see chapter 6 by Rivas-Torres and Rivas in this volume for study site and species details). Within the Galapagos, *Cedrela* is a highly valued timber species for the local, on-island market. The tree is native to tropical America, ranging from central Mexico to Brazil; but despite this wide distribution, its population densities (strongly diminished by illegal and legal logging) are considered low within this native range. Ironically, although it is invasive in the Galapagos, the tree is protected from extraction and even categorized as broadly threatened and vulnerable within its native distribution (IUCN Red List 2016).

Cedrela is well known around the world for its excellent wood quality, which is one of the reasons it was exported to sites outside of its original range and introduced to many Pacific archipelagos like Hawaii and Galapagos (Cintron 1990). *Cedrela* is now the main timber resource in the Galapagos, and its wood is mostly used locally for furniture for the ~30,000 inhabitants and handicrafts for the tourism industry, which includes ~170,000 visitors to the islands (Gardener and Grenier 2011). The annual market value of *Cedrela* timber in the Galapagos local market is estimated to be US$2,000,000 (http://www.cdfdevelopment.org/our-work/biodiversityconservation.html Charles Darwin Foundation 2012), although this rough estimate represents a rare data point on the potential impacts of *Cedrela* management.

Seven decades after its intentional introduction, *Cedrela* is dominating the canopy of several forested areas and invading some of the principal ecosystems of the

archipelago (Renteria and Buddenhagen 2006; Trueman et al. 2014), causing negative ecological impacts (see chapter 6 on allelopathy by Rivas-Torres and Rivas in this volume). In 2007, due to its threatened status in the American continent, the extraction of *Cedrela* was prohibited everywhere in Ecuador including the Galapagos (Ministerio del Ambiente, Acuerdo 167, Articulo 1, 2007). However, in 2009, the extraction of *Cedrela* was allowed to restart in the islands but mostly in the agricultural areas of Santa Cruz, i.e., not intensively in the protected zone where *Cedrela* dominates. Since then, the GNP has been regulating the extraction of *Cedrela*, mainly outside of the protected area by providing permits to users that specify location and timing of *Cedrela* extraction. The GNP is in the planning stages of a new rule incorporating *Cedrela* extraction into their restoration efforts (Galapagos Management Plan, Galapagos National Park Directorate 2014: 199), which presents a unique opportunity to assess how a change in the *Cedrela* market in Santa Cruz affects stakeholders.

Study Area

In the Galapagos, the biggest naturalized population of *Cedrela* (i.e., established without human intervention) exists on Santa Cruz Island, where the tree is considered invasive and is even dominating extensive areas. An ongoing project using satellite images and drones and mapping (for the first time with a peer reviewed and open methodology) the actual coverage of most invasive plants in the Galapagos (Rivas-Torres et al. 2016; http://institutodegeografia.org/vega-2/), recorded that this invasive tree now dominates a block of ~1000 hectares of continuous forest [hereafter also called "*Cedrela* forest"] in that island alone . *Cedrela* forest covers a portion of the humid highlands in the southern side of Santa Cruz at ~200 masl, around 5 km from the main site where *Cedrela* was first introduced. This forest is in the protected area, on the border ("buffer zone") that divides the developing agricultural zone with the National Park (see map on chapter 6). Given its location, the GNP has the authority to decide any actions—such as management and restoration plans—that must be taken in this invasive-dominated forest. In fact, the GNP spends on average US$132,000 per year on *Cedrela*-related restoration activities, including the operation of a greenhouse near the *Cedrela* forest that can produce 60,000 native seedlings to support restoration projects in this highly invaded zone. Outside this forest, *Cedrela* is found mainly on private lands within the "agricultural zone" in Santa Cruz and in small patches or as single individuals extending along steep hillsides. Although the GNP has a prohibition on planting or propagating *Cedrela* throughout the entire archipelago (Gardener et al. 2013), its many wind-dispersed seeds allow it to disperse naturally and colonize other ecosystems outside the block (Renteria and Buddenhagen 2006).

Ecological Data

To summarize the ecological impacts *Cedrela* may have over native and invasive plants, we tabulated the results from relevant investigations measuring invasive tree impacts (i.e., Jaeger et al. 2007) and observations by G. Rivas-Torres (and Rivas-Torres et al. 2017). Some of its main and obvious ecological impacts are related to changes in plant composition and environmental conditions of the sites this tree invades, such as changes in solar radiation to the forest understory and allelopathic effects (Rivas-Torres and Rivas' chapter 6 in this volume) that can limit growth of seedlings and juveniles.

Socioeconomic Data

Cedrela management approaches and associated costs were assessed based on in-field observations and surveys with key stakeholders. Next, we quantified the GNP's management costs for reversing the negative ecological impacts by this invasive tree (Annex 1 [Online]: Table 11.1). This quantification was performed using the Annual Operating Plan (AOP) (Galapagos National Park Directorate 2014), which is part of the Galapagos Management Plan (Galapagos National Park Directorate 2014), and includes detailed information on the yearly budget used by the GNP to perform restoration-type activities. We used the GNP's greenhouse and detailed expense database reported as part of the AOP (2015) to estimate management costs (see, e.g., Annex 1: Tables 11.1 and 11.2) and then projected the costs onto the entire ~1000 hectares which comprise the *Cedrela* forest. This invaded site was selected because it is the first likely target for restoration efforts due to GNP's control over the area and high density of *Cedrela*.

For almost 2 years, G. Rivas-Torres accompanied GNP staff and other park workers (e.g., informal loggers hired to extract *Cedrela* as part of a treatment) and observed day-to-day restoration practices and identified the primary stakeholders involved in *Cedrela* management and its wood market. We identified four primary stakeholder groups (GNP staff, handcrafters, and chainsaw and sawmill workers), which were interviewed to confirm in-field observations about their roles, to understand their participation in the *Cedrela* market and help contextualize the socioeconomic importance of *Cedrela*. Based on a series of interviews with these stakeholders, we developed a survey instrument to (1) define the involved stakeholders, (2) describe the activities they perform in the actual extraction of *Cedrela*, and (3) identify other potential users and participants of this wood market (for answers and methods details, please refer to Annex 1, Tables 11.3 and 11.4; and Annex 2, Figs. 11.4 and 11.5). The data informed a conceptual map identifying the main stakeholders for this market (Fig. 11.1).

To create the qualitative model for the Galapagos *Cedrela* market, we used three main sources: 2+ years of in-field interactions with the identified groups, the conceptual stakeholders' map (Fig. 11.1), and the relevant answers from the sur-

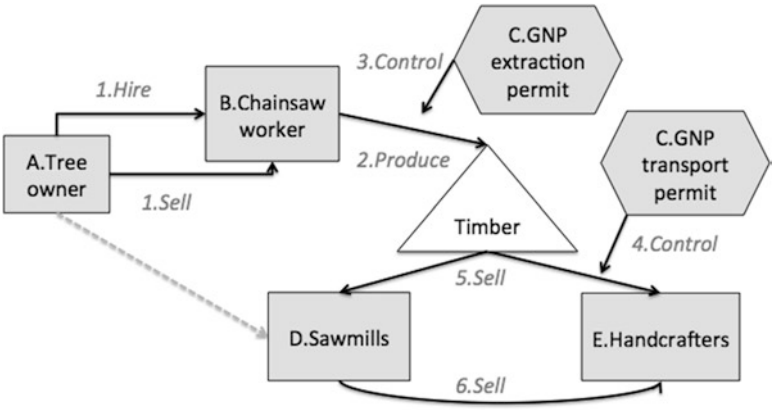

Fig. 11.1 Conceptual map denoting the five primary stakeholder groups in the *Cedrela* wood market in Santa Cruz, Galapagos Islands. The first connection links the tree owner selling the *Cedrela* tree or hiring a chainsaw worker to do the extraction. This action is followed by the production of a timber product by the chainsaw workers who obtain the logs from the felled tree onsite. At this stage, either the chainsaw worker or the previous or new owner of this timber product has the extraction and transport permit approved from the GNP, which controls the extraction process. After getting this permit, *Cedrela* logs and planks are transported and sold to either sawmills or handcrafters. The handcrafters can also buy wood from the sawmills after it has been bought from the original owner

veys, such as costs related to *Cedrela* products and how they differ between stakeholders (i.e., Annex 1, Tables 11.3 and 11.4; and Annex 2, Figs. 11.4 and 11.5). Income data from the surveys informed our predicted impacts model (Fig. 11.2). This exercise also helped identify critical information gaps that should be filled to reduce uncertainty in the decision-making process.

Status Quo and Alternative Models Assembly

According to section 2.1.2 of the Galapagos Management Plan (Galapagos National Park Directorate 2014), one of the main objectives of the GNP is to "Ensure the rational use of supply services generated by ecosystems." This objective is reinforced in subsection 2.1.2.5: "Generate and implement a comprehensive management plan on introduced timber species in coordination with relevant entities." To provide relevant information to help fulfill this objective, we assembled an alternative qualitative model that analyzed how the present model depicting the wood market status quo, and how stakeholders using *Cedrela* in Galapagos, are affected by an integrative GNP plan to manage this invasive tree. Since *Cedrela* is an invasive plant regulated by the GNP, by extension, this plan hypothetically (i.e., stated by this study but not yet implemented) also deals with controlling its extraction both inside and out of the boundaries of the protected area. We built the alternative model under

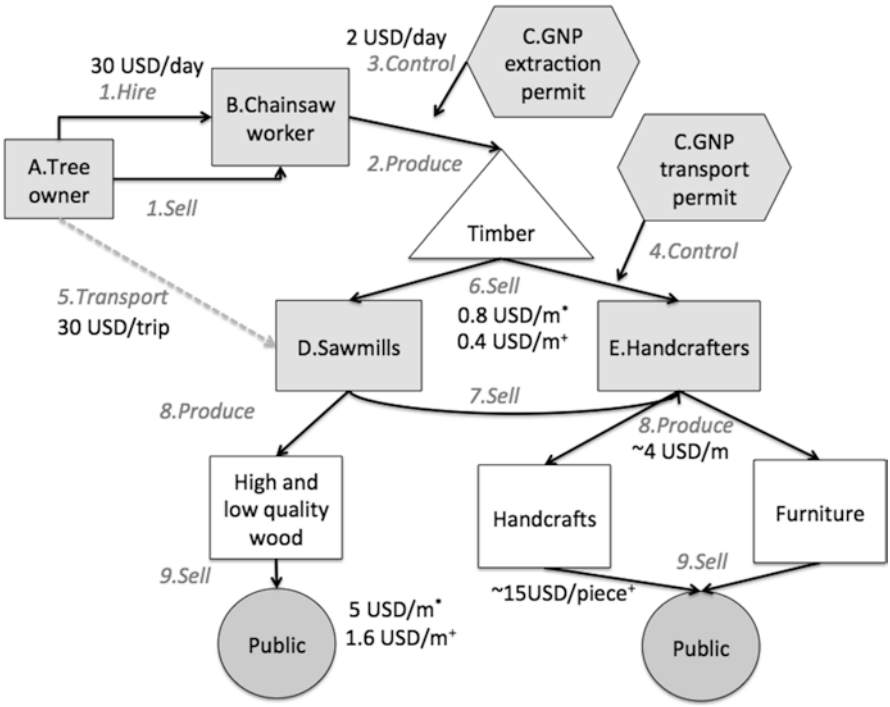

Fig. 11.2 Hypothetical qualitative model for the present *Cedrela* ("*status quo*") wood market in Santa Cruz Island, Galapagos. Stakeholders are presented in dark gray, while products are presented in white. Different steps or transitions are denoted by a number, and are presented in light gray. Prices for different steps are presented where information was available. For definition of *high quality wood and +lower quality wood please refer to notes in Annex 1 Table 11.3

the assumptions that the Park will establish a logging and management plan for the *Cedrela* forest and will also manage and control *Cedrela* planted on private lands (Fig. 11.3).

Results

We identified two main impacts related to the presence and extraction of this invasive tree. First, when *Cedrela* is present, it can significantly reduce the establishment and growth of other native canopy species (i.e., by using allelopathic mechanisms, i.e., Chapter 6 by Rivas-Torres and Rivas of this volume), and, second, when this tree is extracted, other invasive species can take over the restored sites (Jaeger and Kowarik 2010; Annex 1: Table 11.1, "Impact"). For managing the impact to native plants caused by the presence (shade) of *Cedrela*, we first determined (using available literature and restoration plans) that clear-cuts of *Cedrela*

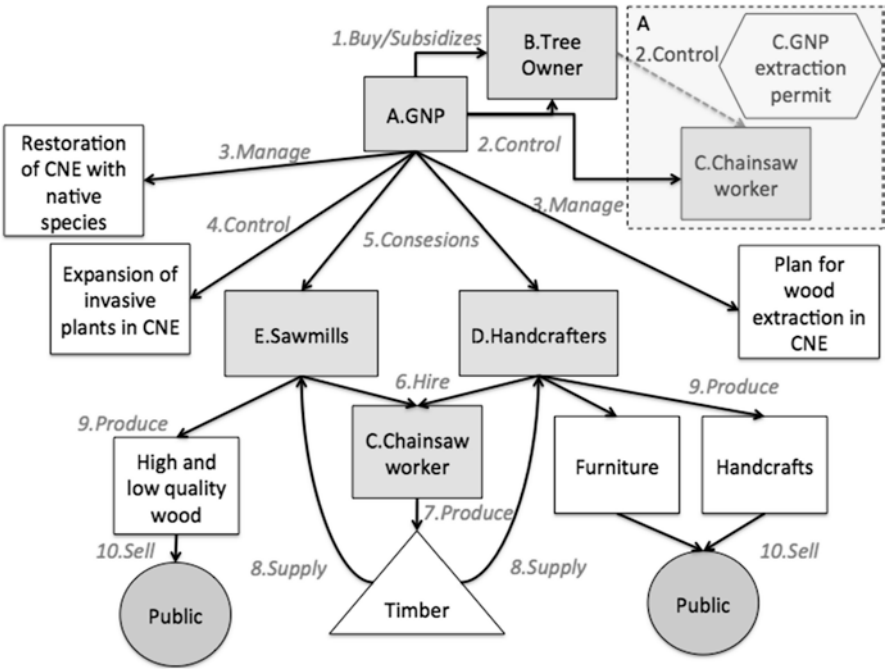

Fig. 11.3 Alternative hypothetical qualitative model for the *Cedrela* wood market in Santa Cruz Island, Galapagos. Stakeholders are presented in dark gray. Different steps or transitions are denoted by a number and are presented in black captions. This model suggests that the steps 3 and 4, i.e. the restoration of *Cedrela* novel forest, the creation of a plan to manage wood extraction and the control of the expansion of invasive plants in this and other extraction sites, should be performed by the GNP if this agency assumes the integral control of the *Cedrela* market. A box is showing the path GNP will have to take if buying a tree from the *Cedrela* owner, which will then follow a similar path as in model of Fig. 11.2

(e.g., Jaeger and Kowarik 2010), followed by reforestation with native seedlings (e.g., Gardener et al. 2009) to increase native propagules pressure (Wilkinson et al. 2005), are preferred. From an ecological perspective and considering GNP objectives, we determined that mechanical (and to a lesser extent, chemical) control is the most appropriate activity (see, e.g., Renteria et al. 2006) to reduce the establishment and expansion of other invasive species after *Cedrela* extraction.

Using the GNP Annual Operative Plan (Galapagos National Park Directorate 2014), specifically the expense section detailed per item and the greenhouse detailed expenses from the Ecosystems Unit of the GNP, we matched each item related to clear-cut of invaded areas, seedling production, reforestation with native seedlings, and mechanical and chemical control of restored areas that the GNP usually performs in other restoration projects. The values calculated for all the items of these four different activities were used to monetize and project the costs for the restoration of the ~1000 hectares that form the *Cedrela* forest. In total, we calculated that a gross amount of US$7,440,000 is necessary to clear-cut, produce the necessary

seedlings to restore the extracted sites, plant native seedlings, and maintain them in initial stages, if the entire 1000 ha block of *Cedrela* forest is to be restored (Annex 1: Table 11.1).

After more than 2 years of interaction with the identified groups, the relevant answers from the surveys (Annexes 1 and 2 and more results on Annex 4) and direct discussions with GNP staff allowed us to create a preliminary stakeholders' diagram (or "systems thinking diagram," Bosch et al. 2007) that was formed mainly by five well-defined groups: private tree owners, chainsaw workers, the Galapagos National Park, sawmill workers, and handcrafters. This preliminary diagram (Fig. 11.1) was shared with and validated by GNP staff. The resulting diagram with the five defined stakeholder groups consisted of six connections. These "connections," or relations between stakeholders, are important to define because they can inform future managerial actions such as restoration or planned extraction of invasive trees and can ensure the success of such conservation initiatives (Ford-Thompson et al. 2012).

After creating the socioeconomic model for the ongoing (i.e., "status quo") *Cedrela* market (Fig. 11.2), we described the preliminary impacts of adopting a new management policy (i.e., manage and control *Cedrela* extraction inside and outside the protected GNP) and how some activities might help to ameliorate these effects. Thus, using the "status quo" conceptual model to describe these expected impacts, we identified that:

First, the GNP would have to establish some mechanisms if taking total control of *Cedrela* management, such as buying adult trees and subsidizing private owners (Dehnen-Schmutz et al. 2004), in order to stop *Cedrela*'s extraction and plantation in private lands (Fig. 11.3, step 1). If the private owners decide to sell the standing *Cedrela* trees to GNP, then this agency would have to supervise the extraction of these trees (Fig. 11.3, step 2, box A) and follow similar steps as presented in the "status quo" model (Fig. 11.3, from step 1: "hire"—onwards).

Second, to meet the actual demand for wood in the archipelago, on one hand, the GNP would have to create and implement a management plan for sustainable extraction (Richardson 1998) of *Cedrela* wood from the *Cedrela* forest (which concentrates the higher density of *Cedrela* trees) and, on the other hand, assume the costs related to the ecological restoration with the desired native species for sites where *Cedrela* would be extracted (Fig. 11.3, step 3).

Third, parallel to a restoration plan, GNP should contemplate the expansion control of other invasive species that could establish and colonize in extracted sites within the *Cedrela* forest. Experimental plots are currently established in this site to understand forest dynamics in this "novel" ecosystem.

Fourth, for those trees to be extracted from the *Cedrela* forest, GNP could arrange concession areas identified for removal to sawmills and handcrafters (Fig. 11.3, step 5), who would be in charge of obtaining the resources and hiring the personnel to extract the wood from those areas and produce the derived goods (Fig. 11.3, steps 6–10), following (more or less) the steps detailed in the first "status quo" model (Fig. 11.3). Concessions by the GNP to extract *Cedrela* within the

~1000 ha are suggested as an alternative based on the understanding that the actual *Cedrela* extraction (i.e., clear-cut to prepare the sites for restoration) represents the most expensive cost among the different activities that are necessary to restore this invaded forest (Annex 1: Table 11.1) and might be a good option to reduce the National Park's expenses.

Discussion

This analysis allowed us to identify the main stakeholders in the *Cedrela* market, assess the importance of *Cedrela* for these stakeholders and Galapagos' society and economy, and, most importantly, analyze the impacts to stakeholders if a different management alternative is implemented in this timber market. Since *Cedrela* is the main source of wood for this tropical archipelago, it is essential to create a plan to manage this highly significant timber source; but, as expected, the importance of *Cedrela* in Galapagos' society represents a potential barrier to future *Cedrela* management projects (Marshall et al. 2011). For instance, this study identified stakeholders in the *Cedrela* market, in particular the ones that depend entirely on the availability of its wood, such as handcrafters, who will be negatively affected if timber availability from this invasive species is reduced or eliminated.

After recognizing target groups that could be affected by potential management action involving *Cedrela* extraction and control (to reduce its ecological impacts), decision-makers (in this case the GNP) may want to include these stakeholders in the management process to reduce the probability of conservation project failure (Glen et al. 2013). Additionally, information and education campaigns that include impacted actors could be robust tools to inform them about the indirect and direct benefits of controlling *Cedrela* for the Galapagos community and help to engage them in an intended management project. These campaigns could also include follow-up surveys to evaluate stakeholders' perceptions about the management action of controlling *Cedrela*, information that could be included to reduce social impacts of this action and thus increase project effectiveness (García-Llorente et al. 2008). Other investigations have shown that active participation and information transfer among stakeholders are helpful to obtain sustainable logging and restoration initiatives (Larson et al. 2011) and if well-implemented might also reduce the impacts on affected social groups (García-Llorente et al. 2008).

One key factor identified by this study that might help to implement such campaigns is that, in spite of the lack of interest to get subsidies from the governmental agencies, handcrafters are open to wood alternatives that could replace *Cedrela* timber (Annex 2: Fig. 11.4). This might be advantageous if a full eradication program is intended for this timber species. In the long run, GNP should consider the eradication of *Cedrela* as this is an invasive species causing impacts within a World Heritage Site. Nevertheless, all the alternative woody species defined by handcrafters are considered non-native species (Annex 2: Fig. 11.5), and so, the use of these trees as substitutes of *Cedrela* will need to be carefully analyzed.

The resulting "status quo" model presented in this study (Fig. 11.2) identified the stakeholders that are presently part of this timber market. It depicts how chainsaw workers, sawmill workers, and handcrafters directly interact with each other (and with other stakeholders such as tree owners) and the public in general, while the GNP mainly controls the extraction and transport of wood within the Galapagos boundaries. This model also shows how prices of the different products and services offered by stakeholders can drastically change throughout the market, like the six-fold additional price a high-quality wood piece can cost in the sawmills when compared to the prices quoted by chainsaw workers. These prices can serve as a reference if the GNP agency implements logging and management programs in the *Cedrela* forest and needs to consider costs of subsidies and other economic intervention strategies to reduce the impact of a market change.

In that regard, the alternative model (Fig. 11.3) diagrams how the different stakeholders and steps would likely be affected if the GNP agency establishes an integrative plan to manage the *Cedrela* extraction in Galapagos and if it implements a logging plan for the *Cedrela* forest. The important change in this alternative model (Fig. 11.3), when compared to the "status quo" model (Fig. 11.2), is the number of activities the GNP agency would have to cover in order to acquire the control of this market. The implementation of some activities recognized to help in the efficient management of timber species like *Cedrela*, such as subsidies, education campaigns (McDermott et al. 2013), active workshops with stakeholders and society (Rea and Storrs 1999), a logging plan, and the active control of colonizing invaders in extraction sites (Jaeger and Kowarik 2010), would definitely increase the operating costs that this governmental agency would need, to manage *Cedrela* forest and *Cedrela* in general. But, after step 4 of the alternative model (Fig. 11.3), i.e., control of the expanding invasive plants in extraction sites, the Park would not need to invest significant amounts of time and money since the next stages are already established for this market.

Similar to other systems where non-native trees have invaded, *Cedrela* has greatly altered native forests in the Galapagos, and a return to native forests requires extensive—but potentially feasible—restoration efforts (Meyer and Florence 1996; Jaeger et al. 2007; Rivas-Torres et al. 2017). Such efforts, as identified by the present empirical analysis, would directly impact the GNP (activities and budget). Indeed, some have suggested that restoration using native species is the only way to restore ecological function of historical forests after tree invasion (Jaeger and Kowarik 2010). If the GNP decides to restore the *Cedrela* forest to resemble native vegetation, it will have to extract *Cedrela* trees so that other native arboreal species, such as *Scalesia pedunculata* (which co-dominated this area in the past), can reestablish in the site as a first step. Restoration of *Cedrela*-dominated sites would also mean, among other things, eradicating adult trees that are inside the agricultural land (i.e., outside the protected area) and that can produce seeds that might colonize restored sites. Due to the capacity of adult *Cedrela* trees to produce winged seeds that can colonize distant sites, we proposed that GNP also should control the production of propagules outside of the protected area, which could impact other social groups (such as tree owners) and might need to involve strategies such as

buying adult trees located in private lands and subsidizing this group of stakeholders (Fig. 11.3, step 1). Opening the canopy after *Cedrela* extraction might also mean other very pervasive invasive species could colonize and outcompete native plants (Renteria 2012). If the GNP does not invest sufficient effort in controlling the colonization of noxious invasive species (such as *Rubus niveus* and *Cedrela*) on newly opened extraction sites, these weeds might then dominate the landscape. Species like *R. niveus* grow very rapidly in open areas forming dense stands, inhibiting recruitment of other plants underneath (Renteria 2012). This is why (as outlined in Annex 1: Table 11.1) the GNP will need to plant native seedlings (previously nurtured in the greenhouse) and control mechanically—or when necessary, chemically—the recruitment of other invasive plants. Relevant studies highlight that a good restoration strategy has to include post-reforestation activities (in this case control of invasive plants colonization) that will help to ensure the sustainability of the restored forest (Jaeger and Kowarik 2010; Meyer 2014). Also, for Galapagos, the mechanical control of invasive plants has been recognized as highly effective, especially when performed in the initial stages of colonization (Gardener et al. 2010; Renteria et al. 2012).

The calculations of gross costs per each activity needed to reverse *Cedrela* impacts were obtained after projecting the present costs for the same managerial actions performed by the GNP in other areas subjected to restoration. Such costs are simply for reference and would have to be adjusted in the future depending on new economic and climatic circumstances. For example, the GNP would need to define contingency plans—and budgets—in case of natural phenomena like El Niño and La Niña or climate change-related events occurring, which may significantly affect the establishment of the planted native seedlings in restored areas because of drought or excessive rain (Trueman and d'Ozouville 2010). On the other hand, positive values on the presence of *Cedrela* forest—such as refuge for some native plants and large native herbivores like the giant Galapagos turtles, which are apparently finding food in invasive-dominated areas (Blake et al. 2012)—can be also included in the balance for the evaluation of costs and benefits of *Cedrela*-dominated site restoration. It is worth mentioning that the costs presented here are only for the entire 1000 hectares that form the *Cedrela* forest, meaning the GNP will not have to invest these amounts in full when beginning with this site's management. Such costs could be covered gradually as the restoration efforts advance for the *Cedrela* forest.

It is still necessary to define if the GNP would be extracting timber from *Cedrela* forest—and/or other infested areas—until no more trees are available and invaded sites are restored and hopefully *Cedrela* is eradicated or if this agency will implement a logging plan that includes the actual crop and regeneration of *Cedrela* wood patches inside this forest that can help to supply and maintain the wood market in Galapagos. If the Park chose the latter, the costs presented in this study would increase substantially since some of the detailed activities, like the actual extraction and the post-extraction control of invaders, would have to be replicated several times per extraction patch/site and event. However, active wood production from the *Cedrela* forest could also be a significant income source for the Park, who could use

the revenues from this activity for the control and management of this and other areas, and also—for instance—for subsidy payments to the private sector that might be affected by its exclusion from the *Cedrela* market. On the other hand, if the GNP chooses the former, desired *Cedrela* eradication might be achieved due to the exhaustion of this timber source, but in this case, the GNP would have to provide alternatives to the future absence of *Cedrela* timber in this closed market, which should be explored before beginning with the *Cedrela* extractions.

The two models presented here were empirically derived based on best available data and observations and on surveys that occurred over 2 years in the field, and they present the most detailed description to date of the wood market in Galapagos. The models were also verified with stakeholders. Still, these systems are not static, and future work is needed to revisit these models and revise them, perhaps including results from restoration techniques and feasibility to reconvert novel areas, different actors and users within the *Cedrela* wood market, and new socioeconomic impacts from changes in the management of the wood market for this invasive but economically valuable species. Nevertheless, we anticipate that the multidimensional analytical models here presented (i.e., that include the ecological impacts in addition to the socioeconomic aspects) will be useful for establishing conservation strategies and management priorities. These models identify which, and how, stakeholders might be impacted under alternative potential managerial scenarios, information that might be critical if new conservation programs intended to manage invasive timber species are established (Hulme 2006). They may also inform policy choices and decision-making processes for the management of other invasive timber species in the Galapagos archipelago and other highly invaded and inhabited areas where similar conservation conflicts might occur.

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Annex 1

Table 11.1 Defined impacts caused by the presence and extraction of *Cedrela odorata* on native and non-native plant species and the corresponding activities and costs that are necessary to revert them

	Impact	Management	Activity	Units	Cost[a]
1	*Cedrela* shade and addition of chemical compounds of this species to soil, significantly reduces establishment and growth of other native canopy species like *Scalesia pedunculata, Psychotria rufipes*, and *Psidium galapageium*	*Cedrela* extraction for restoration purposes	Clear-cut *Cedrela*, site cleaning, and preparation for reforestation	Hectare	US$20 per day × 3 workers × 10 days Total = $6200 per hectare = $4,960,000 for 800 hectares
		Reforestation with native seedlings	Produce seedlings[b]	Seedling	US$1.60 to produce a viable seedling × ~$500,000 needed for 800 hectares = $800,000
			Plant seedlings in the field and maintain and control restored site for native plants' survival	Seedling	US$1.68 per plant in a year × $500,000 for the 800 hectares = $840,000
2	Individual extraction of *Cedrela* adult trees significantly increases the probability of growth and establishment of other invasive plants like *Rubus niveus* and *Cestrum auriculatum*	Control of invasive species after *Cedrela* extraction	Perform mechanical and chemical control for *Cedrela* seedlings and other invasive species, establishing and colonizing after *Cedrela* extraction	Hectare	US$1.05 per hectare in a year × 800 hectares = $840,000
			GROSS TOTAL = US$ 7.440.000		

Note: [a]Costs were calculated after projecting the costs defined in the AOP of the GNP that are specified for restoration purposes
[b]Seedlings are produced in the GNP greenhouse

Table 11.2 Detailed items necessary to produce and maintain 60,720 native seedlings in the GNP Ecosystem Unit's greenhouse and reference labor and restoration costs

Input	Amount	Units	Unit Cost (US$)	Total (US$)
Compost	173	Bag	5	865
Black gravel	2	Truck	128	256
Soil	2	Truck	160	320
TS-1 (hormone, 30 kg)	345	Bag	36	12.42
Novaplex	80	Litter	20.9	1.67
Radical	40	Litter	11.4	456
Water (10.000 L)	10	Tanker	150	1.50

Input	Amount	Units	Unit Cost (US$)	Total (US$)
Subtotal				17.48
Subtotal/60,720 seedlings[a]				0.29
Materials				
Hose	17	Unit	11.59	197.05
Fumigation pump (15 L)	1	Unit	56.93	56.93
Fumigation pump (20 L)	4	Unit	70.41	281.66
Biodegradable plastic bags	600	Unit	5	3.00
Plastic sack (10 G)	12	Unit	8.41	100.99
Plastic containers	43	Unit	10.49	451.24
Large machetes (24 in.)	4	Unit	3.43	13.73
Small machetes (16 in.)	4	Unit	3	12.00
Shovel	10	Unit	17.25	172.58
Black flat plastic	50	Meter	1.89	94.76
Sacks	100	Unit	0.95	95.15
Plastic tank (250 Gl)	4	Unit	345.17	1380.68
Large plastic tank (5000 L)	4	Unit	552.28	2209.12
Subtotal				8065.89
Subtotal/60,720 seedlings				0.13
Maintenance				
Paintbrushes (1 in.)	13	Unit	1.2	15.9
Metallic brushes	8	Unit	1.9	14.9
Pressure hose	45	Meter	1.7	77.4
Irrigation hose	400	Meter	1.9	760.0
Grafting knives	5	Unit	80	399.8
White paint	10	Liter	3	29.9
Greenhouse cloth (60% × 100 m)	10	Meter	250	2500
Pruning scissors (6 in.)	12	Unit	28	342.0
Subtotal				4139.8
Subtotal/60,720 seedlings				0.07
Labor				
Public server, status 1	2	Unit	1710	3.42
Public server, status 2	2	Unit	1110	2.22
Subtotal				67.68
Subtotal/60,720 seedlings				1.11
Reforestation				
Mechanic and chemical control and reforestation (40 hectares[b])	1	Unit	1.050	42,000
Subtotal				42,000
Subtotal/60,720 seedlings				1.68
Production cost per plant				1.6

"AMOUNT" refers to the number of units necessary to produce and maintain this number of seedlings in ~1 year. This information was mainly used to define "COSTS" in Table 11.1

[a]Total plant capacity of GNP's greenhouse

[b]Reference price from restoration projects in Santa Cruz (2014)

Table 11.3 Detail of the survey questions given to four of the five identified stakeholders (not to "tree owners") of the *Cedrela* wood market in Galapagos

#	Stakeholder	Concept	Type of question	Question	Response category	Level of measurement response
1	GNP staff	ROLE	OPEN-ENDED	What is the main objective of Galapagos National Park (GNP) regarding plant-introduced species (IS)?	Fill in the blank	CONTINUOUS
2	GNP staff	ROLE	OPEN-ENDED	From your point of view, what are the main necessities for the control of IS?	Fill in the blank	CONTINUOUS
3	GNP staff	INFORMATIVE	OPEN-ENDED	What are the benefits to restore invaded native forests?	Fill in the blank	CONTINUOUS
4	GNP staff	INFORMATIVE	OPEN-ENDED	Is there an implemented system to measure the restoration benefits?	Fill in the blank	CONTINUOUS
5	GNP staff	INFORMATIVE	OPEN-ENDED	Is there an implemented system to measure the post-restoration effects?	Fill in the blank	CONTINUOUS
6	GNP staff	INFORMATIVE	OPEN-ENDED	Are there any benefits for not restoring and/or eradicating/controlling the *Cedrela* novel ecosystem?	Fill in the blank	CONTINUOUS
7	GNP staff	INFORMATIVE	OPEN-ENDED	How do you think the IS control costs could be minimized?	Fill in the blank	CONTINUOUS
8	GNP staff	INFORMATIVE	OPEN-ENDED	Is *Cedrela* a species of concern for the GNP?	Fill in the blank	CONTINUOUS
9	GNP staff	INFORMATIVE	OPEN-ENDED	What are the benefits of the *Cedrela*-dominated forest?	Fill in the blank	CONTINUOUS
10	GNP staff	INFORMATIVE	OPEN-ENDED	What are the impacts of the *Cedrela*-dominated forest?	Fill in the blank	CONTINUOUS
11	GNP staff	SUBSTITUTABILITY	OPEN-ENDED	If you are able to duplicate your budget for the control and monitoring task, what do you change in your actual planning and why?	Fill in the blank	CONTINUOUS
12	GNP staff	SUBSTITUTABILITY	OPEN-ENDED	Do you think it will be more efficient to have a major influx of money invested in the first stages for the control and monitoring of IS than the current budget schedule?	Fill in the blank	CONTINUOUS

#	Stakeholder	Concept	Type of question	Question	Response category	Level of measurement response
13	Handcrafters	PARTICIPATION	CLOSE-ENDED	Do you know of any farm or place/people who are growing timber species like sauco macho (*Citharexylum gentryi*)?	YES/NO	DICHOTOMOUS
14	Handcrafters	USE	CLOSE-ENDED	Which species do you know are planted in farms growing/managing timber products?	Cedrela	CATEGORICAL
					Guava	
					Teak	
					Cinchona	
					Laurel	
					Chanul	
					Mahogany	
					Balsa	
					Aguacate	
					Guayabillo	
15	Handcrafters	INCOME	CLOSE-ENDED	Do you sell sauco macho (*Citharexylum gentryi*)?	YES/NO	DICHOTOMOUS
16	Handcrafters	INCOME	CLOSE-ENDED	Do you sell guava (*Psidium guajava*)?	YES/NO	DICHOTOMOUS
17	Handcrafters	PARTICIPATION	CLOSE-ENDED	It is because buyers prefer other species?	YES/NO	DICHOTOMOUS
18	Handcrafters	PARTICIPATION	CLOSE-ENDED	What uses do you think the people might be giving guava wood?	Coal	CATEGORICAL
					Furniture	
					Handcrafts	
					Construction	
					Don’t know	
					NO ANSWER	
19	Handcrafters	INCOME	CLOSE-ENDED	Do you mainly sell *Cedrela*?	YES/NO	DICHOTOMOUS

#	Stakeholder	Concept	Type of question	Question	Response category	Level of measurement response
20	Handcrafters	INCOME	CLOSE-ENDED	Which other woody species do you mostly sell?	Guava	CATEGORICAL
					Teak	
					Quinine	
					Laurel	
					Chanul	
					Mahogany	
					Balsa	
					Aguacate	
					NO ANSWER	
21	Handcrafters	PARTICIPATION	CLOSE-ENDED	Where do you obtain wood from these species?	Third parties	CATEGORICAL
					Own farm	
					From the continent	
					NO ANSWER	
22	Handcrafters	PARTICIPATION	CLOSE-ENDED	Where do you obtain *Cedrela* wood?	Third parties	CATEGORICAL
					Own farm	
					From the continent	
					NO ANSWER	
23	Handcrafters	INCOME	CLOSE-ENDED	For what purpose do you mostly buy or use *Cedrela* wood?	Furniture	CATEGORICAL
					Construction	
					NO ANSWER	
24	Handcrafters	SUBSTITUTABILITY	CLOSE-ENDED	Do you think there are potential substitutes for woody species such as *Cedrela*?	YES/NO	DICHOTOMOUS
25	Handcrafters	INCOME	CLOSE-ENDED	If you have *Cedrela* wood for sale, how much do you ask for a unit (define a unit)?	Fill in the blank	CATEGORICAL

#	Stakeholder	Concept	Type of question	Question	Response category	Level of measurement response
26	Handcrafters	SUBSTITUTABILITY	CLOSE-ENDED	Would you be interested in planting a different species instead of *Cedrela* if the government/local authorities offer you other plants?	YES/NO	DICHOTOMOUS
27	Handcrafters	SUBSTITUTABILITY	CLOSE-ENDED	If yes, which plant would you be willing to accept as an alternative?	Mahogany	CATEGORICAL
					Nogal	
					Laurel	
					Teca	
					Alcanfor	
					NO ANSWER	
28	Handcrafters	SUBSTITUTABILITY	CLOSE-ENDED	Would you be interested to stop using *Cedrela* if the government/local authorities offer you to pay for it?	YES/NO	DICHOTOMOUS
29	Chainsaw	INCOME	CLOSE-ENDED	How much are you paid for a whole day's work?	Fill in the blank	CONTINUOUS
30	Chainsaw	INFORMATIVE	CLOSE-ENDED	What are the average sizes of the trees you look to cut?	Fill in the blank	CONTINUOUS
31	Chainsaw	INFORMATIVE	OPEN-ENDED	How many pieces of wood you can obtain from a tree of those dimensions?	Fill in the blank	CONTINUOUS
32	Chainsaw	INFORMATIVE	OPEN-ENDED	What is the size of wood logs do you obtain?	Fill in the blank	CONTINUOUS
33	Chainsaw/ sawmill	INCOME	OPEN-ENDED	What is the price of first-quality wood[a] in USD per meter?	Fill in the blank	CONTINUOUS
34	Chainsaw/ sawmill	INCOME	OPEN-ENDED	What is the price of lesser-quality wood[a] in USD per meter?	Fill in the blank	CONTINUOUS
35	Chainsaw/ sawmill	INCOME	OPEN-ENDED	How much do you pay for wood transportation?	Fill in the blank	CONTINUOUS
36	Chainsaw/ sawmill	INCOME	OPEN-ENDED	Is there any GNP fee you pay? If yes, how much is it?	Fill in the blank	CONTINUOUS

#	Stakeholder	Concept	Type of question	Question	Response category	Level of measurement response
37	Chainsaw/ sawmill	SUBSTITUTABILITY	OPEN-ENDED	Is there any other wood you extract or commercialize?	Fill in the blank	CONTINUOUS
38	Sawmill	INFORMATIVE	OPEN-ENDED	What is the diameter of *Cinchona* (cascarilla) that you commercialize?	Fill in the blank	CONTINUOUS
39	Sawmill	INFORMATIVE	OPEN-ENDED	What is the length of *Cinchona* (cascarilla), in meters, that you commercialize?	Fill in the blank	CONTINUOUS
40	Sawmill	INCOME	OPEN-ENDED	What is the price for a 20 cm DBH and 5-m-long log of *Cinchona* (cascarilla) in $US?	Fill in the blank	CONTINUOUS
41	Sawmill	INFORMATIVE	OPEN-ENDED	What is the diameter of bamboo that you commercialize?	Fill in the blank	CONTINUOUS
42	Sawmill	INFORMATIVE	OPEN-ENDED	What is the length of bamboo, in meters, that you commercialize?	Fill in the blank	CONTINUOUS
43	Sawmill	INCOME	OPEN-ENDED	What is the price for a meter of bamboo in $US?	Fill in the blank	CONTINUOUS

Note: [a]Lower-quality wood refers to wood pieces less than 20 cm wide and 3 m long, while good-quality wood describes wood pieces of at least 20 cm wide and 3 m long. Common species names: "guava" *Psidium guajava,* "teak" *Tectona grandis,* "quinine" *Cinchona pubescens,* "laurel" *Cordia alliodora,* "chanul" cf. *Humiriastrum*, "mahogany" *Swietenia macrophylla,* "balsa" *Ochroma pyramidale,* "aguacate" *Persea americana,* "alcanfor" *Centratherum punctatum,* "nogal" *Juglans neotropica,* "guayabillo" *Psidium galapageium,* "bamboo" *Bambusa sp*

Table 11.4 Answers for the 15 questions given to 2 chainsaw and 2 sawmill workers Question details are defined in Table 11.3, from questions 29 to 43

#	Questions	Chainsaw 1	Chainsaw 2	Sawmills 1	Sawmills 2
1	How much are you paid (in USD) for a whole day of work?	$30 USD	$30 USD	NA	NA
2	What are the average trees you look to cut?	100 DBH 15–20 m tall	NA	NA	NA
3	How many pieces of wood you can obtainfrom a tree of those dimensions?	$60	NA	NA	NA
4	What is the size of woodlogs you obtain from felled trees?	3 m by 22 cm wide	3 m by 22 cm wide	NA	NA
5	What is the price you charge for a first quality* wood piece/meter?	$0.8USD	$0.8 USD	$5 USD	$5 USD
6	What is the price you charge for a lesser quality* wood piece/meter?	$0.4 USD	$0.4 USD	$1.6 USD	$1.3 USD
7	How much do you pay for transportation?	$30 USD	$30 USD	$30 USD	$20 USD
8	Is there any fee you pay to GNP?	$2USD	$2 USD	$2 USD	$2 USD
9	Is there any other wood you extract or commercialize?	*Cinchona*	*Cinchona*	*Cinchona*	*Cinchona*, bamboo
10	What is the diameter (in centimeters) of *Cinchona* that you commercialize?	NA	NA	20 DBH	NA
11	What is the length (in meters) of *Cinchona* that you commercialize?	NA	NA	5 m	NA
12	What is the price for a log of 20 centimeters DBH and 5 meters long of *Cinchona*?	NA	NA	$40 USD	NA
13	What is the diameter of bamboo that you commercialize?	NA	NA	NA	10 cms
14	What is the length of bamboo that you commercialize?	NA	NA	NA	3 m and over
15	What is the price for a meter of bamboo?	NA	NA	$0.8 USD	NA

Note: Lower (lesser)- and good-quality wood are defined in Table 11.3

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