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Review

Assessing the impacts of international trade on CITES-listed species: Current practices and opportunities for scientific research

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ABSTRACT

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) came into effect in 1975 to protect certain species of wild fauna and flora against over-exploitation through international trade. Determining which trade is detrimental to the survival of species in the wild can be a major difficulty in the implementation of CITES by national authorities, partly due to limited knowledge and understanding of the species' biology, management, and the impacts of harvesting. Some of this knowledge could be acquired through targeted scientific research. However, to date there exists no general overview of the current use of biological information in determining detriment in CITES to help scientists identify research priorities. For an international meeting in 2008, over 100 scientists and regulators compiled 60 case studies covering a wide range of CITES-listed taxa, outlining how information on the biology, harvesting and management might be used to determine whether international trade is detrimental. We used these case studies, workshop conclusions, and other published literature, to identify 10 potential research directions for the scientific community which, if addressed, could greatly assist in the making of Non-Detriment Findings. We hope that this will encourage more scientists to study CITES-listed species, and foster more collaboration between research scientists, CITES national authorities, CITES technical committees and local communities. The case studies highlight a general need for advice on how to identify and manage levels of risk involved when assessing possible detriment, and for advice on assessing detriment under complex harvesting scenarios such as when multiple species, or parts of individuals, are harvested. Broadly, they highlight an opportunity for scientists to further develop a body of scientific studies that propose, refine and adapt methods for assessing detrimental trade in CITES-listed taxa. Comparisons within life-form groups indicated the potential for the identification of practical advice that could apply to groups of taxa. The case studies highlighted a widespread need for more information gathering studies of CITES-listed taxa such as the broader impacts of harvesting on populations and ecosystems, and the potential long-term evolutionary impacts. The case studies also highlighted the need for practical advice on how to implement adaptive management programmes and for research into enterprises based on the harvesting of CITES-listed species from the wild.

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Contents

1. Introduction

Determining and improving sustainable exploitation practices for wild species has been recognized internationally as an important goal for the future (CBD, 2006; UN, 2008). It is a challenging goal as a variety of interacting factors need to be considered, at least some of which are uncertain or unknown. Many problems faced in achieving sustainability are less to do with understanding the biology of the species and more to do with social, political and economic factors that affect sustainable management practices (Hutton and Dickson, 2001). However, a general lack of knowledge of species biology, and the impacts of harvesting on populations can also make it difficult to identify and decide on sustainable exploitation practices. It is obvious that additional research has the potential to improve our confidence when deciding what is and is not sustainable. Less obvious is what, specifically, scientists can do that is likely to lead to substantial improvements for the future.

In this brief review we identify ten research areas that, if addressed by scientists, would assist in determining sustainable exploitation practices for species covered by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). These research areas were derived from a set of 60 peer reviewed case studies, compiled for an international workshop conducted in 2008 (CITES, 2010; CONABIO, 2008). The case studies feature a wide range of taxa for which experts outlined how they would determine whether exports for international trade would be detrimental to species survival in the wild. The assembly of such a large number of varied case studies was a first for CITES. These were undoubtedly a biased selection of species covered by CITES (details below) but they still provide a broad insight into the use of biological information and present some examples of where important information is deficient in the implementation of the Convention. It is also important to realise that the case studies were not formal accounts of the actual processes used by national authorities to determine detrimental trade. As we will show, the case studies generally highlight that the availability of more biological information would have helped in determining unsustainable trade. Can some of these basic deficiencies be met by raising the awareness of relevant research questions in the scientific community? We believe that while many of the knowledge gaps will be filled over time, it is likely that they could be filled faster and more efficiently if more research scientists study CITES-listed species. We hope that, by highlighting promising research areas, this review will lead to more collaboration between scientists and national authorities in determining sustainable exploitation practices.

To date, a range of studies have reported on aspects of the implementation of CITES for specific CITES-listed taxa or taxon groups (e.g. Carpenter and Robson, 2005; Acosta, 2006; Blundell, 2007; Grogan and Schulze, 2008; Castello and Stewart, 2010; Parsons et al., 2010). Their focus on particular CITES-listed taxa enabled a detailed assessment of factors relevant to determining detrimental trade and led them, in certain cases, to formulate advice on CITES implementation. We note that it is not our goal with this review to critically assess current practices for assessing detrimental trade for specific CITES-listed taxa or more generally.

We begin with an introduction to the Convention, summarising how it aims to ensure that the exploitation of wild resources for international trade is sustainable. We then briefly describe the International Expert Workshop and provide a short overview of the biological information used in those workshop case studies before proceeding to outline our ten recommended areas of scientific research for the future.

1.1. Background to CITES and Non-Detriment Findings (NDFs)

One-hundred and seventy-five countries are currently signatory to CITES, agreeing to ensure that international trade is not detrimental to the survival in the wild of species listed in the CITES Appendices. The term "detrimental" is used throughout the Convention text although no formal definition is given (see Box 1 for the relevant text of the Convention, and CITES (1973) for the full text). Appendix I comprises species threatened with extinction, and which are or may be affected by international trade. Trade in wild specimens of these species for commercial purposes is banned except under exceptional circumstances (CITES, 1973), but exporting countries are still required to assess whether trade has a detrimental impact on the species' survival in the wild. Importing countries also need to determine that the purpose for which the species is imported will not be detrimental to the survival of the species. Appendix II comprises species that may become threatened with extinction unless international trade is regulated in order to avoid utilization incompatible with their survival. In this case, the possible detrimental impact of international trade on wild populations has to be assessed by the exporting country only.

Box 1 The CITES definition of Non-Detriment Finding (NDF) (CITES, 1973).

Article III
Regulation of trade in specimens of species included in Appendix I

2. The export of any specimen of a species included in Appendix I shall require the prior grant and presentation of an export permit. An export permit shall only be granted when the following conditions have been met:

(a) a Scientific Authority of the State of export has advised that such export will not be detrimental to the survival of that species; [. . .]

3. The import of any specimen of a species included in Appendix I shall require the prior grant and presentation of an import permit and either an export permit or a re-export certificate. An import permit shall only be granted when the following conditions have been met:

(a) a Scientific Authority of the State of import has advised that the import will be for purposes which are not detrimental to the survival of the species involved; [. . .]

5. The introduction from the sea of any specimen of a species included in Appendix I shall require the prior grant of a certificate from a Management Authority of the State of introduction. A certificate shall only be granted when the following conditions have been met:

(a) a Scientific Authority of the State of introduction advises that the introduction will not be detrimental to the survival of the species involved; [. . .]

Article IV
Regulation of trade in specimens of species included in Appendix II

2. The export of any specimen of a species included in Appendix II shall require the prior grant and presentation of an export permit. An export permit shall only be granted when the following conditions have been met:

(a) a Scientific Authority of the State of export has advised that such export will not be detrimental to the survival of that species; [. . .]

3. A Scientific Authority in each Party shall monitor both the export permits granted by that State for specimens of species included in Appendix II and the actual exports of such specimens. Whenever a Scientific Authority determines that the export of specimens of any such species should be limited in order to maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs and well above the level at which that species might become eligible for inclusion in Appendix I, the Scientific Authority shall advise the appropriate Management Authority of suitable measures to be taken to limit the grant of export permits for specimens of that species.

6. The introduction from the sea of any specimen of a species included in Appendix II shall require the prior grant of a certificate from a Management Authority of the State of introduction. A certificate shall only be granted when the following conditions have been met:

(a) a Scientific Authority of the State of introduction advises that the introduction will not be detrimental to the survival of the species involved; and [. . .]

In the case of Appendix II species, the Convention text identifies some aspects of "not detrimental" by requiring that export "should be limited in order to maintain that species throughout its range at a level consistent with its role in the ecosystems in which it occurs and well above the level at which that species might become eligible for inclusion in Appendix I". Therefore, all international trade in taxa listed in the two main CITES Appendices must be accompanied by an assessment of the impact of trade on wild populations, termed a Non-Detriment Finding (NDF).

Signatories to CITES are required to designate one or more Scientific Authorities (SA) to make NDFs and to advise the authorities who issue CITES permits (designated as Management Authorities by CITES). There is no specific methodology set by the Convention on how to make NDFs, although resolutions of the Conference of the Parties to CITES provide some further information and guidance (CITES, 1997, 2004). Scientific Authorities do not normally make the reasoning behind NDFs publically available. This makes it difficult to assess whether improvements could be made to current methods, to identify where important knowledge gaps exist, and direct scientific research to improve NDFs.

A thorough scientific understanding of the biology of a species is not always a requirement for determining whether harvesting for international trade is likely to be detrimental to the survival of a species. For example, harvests that are clearly small in relation to the overall abundance or distribution of the species, or those that have been established under an effective adaptive management programme may be quite straightforward to declare as non-detrimental. However for many CITES-listed species, decisions regarding NDFs are not straightforward. For example, the status of the species in the wild may be relatively poorly understood, harvests may be taken from unknown localities, and they could vary in intensity and harvest method. Scientific Authorities usually have to make a relatively rapid decision about NDFs despite often having insufficient data to be confident about precisely what is or is not detrimental. NDFs can therefore be seen as a risk analysis (CITES, 2010; Morgan, 2008), in which SAs have to assess the risk that a particular export (or import in the case of Appendix I) is detrimental as a function of current knowledge and uncertainty. In such cases one might expect that the SA would consider the source, magnitude and frequency of exports in relation to the species biology, management and monitoring systems in place to detect possible detriment. On this assumption, preliminary guidance for making NDFs was developed into a checklist to assist SAs assess the multiple factors that may be important (CITES, 2000; Rosser and Haywood, 2002).

1.2. Workshops to improve NDF making

Subsequent to the checklist of Rosser and Haywood (2002) a number of groups worked on developing guidelines for making NDFs for different taxonomic groups (Austin and Fraser, 2004; CITES, 2005; DEWR, 2007; IUCN-SSC, 2007; MWG, 2005; PC, 2008a,b; Sadovy et al., 2007). In 2008 an international workshop was conducted to provide further guidance to CITES Authorities relating to the information and methods that are or can be used to formulate NDFs (CITES, 2010; CONABIO, 2008). To date, this has been the only workshop to outline NDFs for a wide variety of taxonomic groups. Sixty case studies constituted the core component of the workshop, each outlining details considered relevant by scientists and regulators in making NDFs for specific taxa or taxon groups (the case studies can be accessed through the CONABIO website: see CONABIO, 2008). The workshop achieved broad coverage of the different CITES-listed taxa by creating nine working groups, each focussing on a different "life form" from the CITES Appendices (summarized in Table 1). The Co-Chairs of the working groups then requested case studies from specialists, most of whom

Table 1
Details of the nine life-form groups considered at the 2008 workshop.

Life-form group	No. studies	Taxa covered and corresponding countries/regions represented
Trees	9	*Aquilaria malaccensis*, Malaysia; *Caesalpinia echinata*, Brazil; *Gonystylus bancanus*, Malaysia; *Guaiacum sanctum*, Mexico; *Pericopsis elata*, Cameroon; *Prunus africana*, Cameroon; *Swietenia macrophylla*, Brazil, Bolivia, Peru; *Taxus* spp., Canada
Perennials	7	*Cibotium barometz*, China; *Nardostachys grandiflora*, Himalayan region; *Panax quinquefolius*, Canada, United States; *Perlagonium sidoides*, Lesotho; *Tillandsia xerographica*, Guatemala
Succulents and cycads	7	*Aloe* spp., East Africa; *Carnegia gigantea*, Mexico; *Ceratozamia mirandae*, Mexico; *Cycas circinalis*, India; *Dioon edule*, Mexico; *Encephalartos* spp., South Africa; *Hoodia gordonii*, Southern Africa
Geophytes and epiphytes	7	*Ansellia africana*, Kenya; *Dracula sodiroi*, Ecuador; *Galanthus elwesii*, Turkey; *Galanthus woronowii*, Georgia; *Phragmipedium fischeri*, Ecuador; *Vanda coerulea*, Thailand
Mammals	8	*Macaca fascicularis*, China; *Macaca mulatta*, China; *Monodon monoceros*, Greenland; *Panthera leo*, Tanzania; *Panthera pardus*, South Africa; *Tursiops aduncus*, Solomon Islands; *Ursus arctos*, Canada; *Vicugna vicugna*, Peru
Birds	6	*Amazona auropaliata*, Nicaragua; *Cacatua galerita*, New Zealand; *Cacatua sulphurea*, Indonesia; *Falco cherrug*, United Arab Emirates; *Platycercus eximius*, New Zealand; *Psittacus erithacus*, Guinea
Reptiles	6	*Crocodylus niloticus*, Kenya; *Cuora amboinensis*, Indonesia; *Malacochersus tornieri*, Kenya; *Ptyas mucosus*, Indonesia; *Uromastyx* spp., Israel
Fishes	5	*Acipenser* spp., Northwest Black Sea; *Anguilla anguilla*, Sweden; *Arapaima* spp., Brazil; *Cheilnus undulatus*, Indonesia; *Hippocampus* spp., not specified; *Huso* spp. Northwest Black Sea
Aquatic invertebrates	5	*Antipathes* spp., United States; Coral genera in Queensland Coral Fishery, Australia; Scleractinia, Indonesia; *Strombus gigas*, Colombia; Tridacnidae, Palau

had experience in making NDFs (CITES, 2010). All submitted case studies were peer reviewed by members of the workshop's Academic Subcommittee.

The specialists who compiled the case studies were not doing so on behalf of their governments. Therefore, the data and NDF procedure used by governments may differ from that detailed in the case study reports. The case studies are also likely to be a biased representation of NDFs. For example, Co-Chairs may have selected taxa for which there already exists sufficient information to be relatively confident when formulating an NDF.

The 60 case studies represent a wide range of taxa (Table 1) and provide examples of the formulation of NDFs from every continent except Antarctica. They provide equal coverage of plants and animals and include examples of both aquatic and terrestrial species. Most case studies relate to one species only, although some cover several species, entire genera, or several genera. The case studies also represent a wide range of harvesting scenarios, with around three quarters in which whole individuals are removed from the wild population (extractive harvesting) and around one quarter in which only parts of individuals are removed (non-extractive harvesting). In some case studies, the same species was reported as being subjected to both extractive and non-extractive harvesting.

A formal general summary of the workshop was submitted by the Animals and Plants Committees of CITES to the Conference of the Parties (CITES, 2010), but did not include details of the biological information provided in the case studies. We therefore reviewed the case studies, recording the different types of biological information they considered. Information (biological or otherwise) is presented in inconsistent formats across the case studies: for example some present tables of data, whereas others simply mention the existence of data. This made it impossible to reliably assess the relative quality or quantity of specific types of data on the basis of the information contained in the workshop reports alone. As a result, we were lenient in our summary when we recorded specific biological information as being present: the existence of information simply had to be mentioned in a case study for us to designate it as present. In addition, we noted when the case studies mentioned specific biological information that was currently lacking but that would be useful in the NDF making process. Our findings are summarized in Table 2. Our aim with this summary is to give a concise overview of the different biological details included in the case studies, and an indication of how the availability of biological information varies between the case studies and life forms.

As expected, basic biological information such as the geographical distribution of the taxon and its habitat requirements were provided by almost all of the case studies. Such details are clearly likely to be considered when deciding whether a particular harvest is likely to be detrimental. The majority of studies also outlined detailed information about characteristics of populations of the harvested taxa, such as information on abundance within, or rates of change between, demographic classes or life history stages. Such information is likely to be useful when considering the effects of multiple harvests over time, for example SAs may consider whether the life history of the taxon is likely to be able to support a particular type of repeated harvest.

Information about the effects of harvesting on the populations was less frequently outlined in the case studies, and was highly variable between the different ''life-form'' groups (Table 2). Some 67% of the studies reported effects of harvesting on the population but only 7% reported on the impacts of harvesting on the ecosystem, even though most reported some information on the role of the taxon in the ecosystem (73%). This supports our general impression that detriment was primarily assessed in terms of its effects on the harvested taxon (item 2 in Articles III and IV of Box 1), and less often in terms of the effects on the species role in the ecosystem (item 3 in Article IV of Box 1). A minority of the studies reported information on the recovery rate of the harvested taxon (43%) and only 35% reported information on a sustainable harvesting level. As indicated above, the determination of sustainable harvesting levels is not always required in order to make NDFs, although it is likely to be a consideration when species are subjected to repeated harvests over time (CITES, 1997).

Unsurprisingly the majority of the case studies reported that biological information was used in formulating NDFs (89%), although there are some examples where little or no such information was used. Notably however, the majority of the case studies also identified biological details that would have been useful in NDF formulation, but these aspects of the biology of the particular species were not known (78%). These general findings would probably have been expected by most readers, especially those with experience of CITES, but this is the first time such information has been documented for a wide range of case studies.

In general, there appears to be relatively little peer-reviewed literature on population demography, responses to harvesting, or sustainable use of CITES-listed species. A recent analysis from South Africa showed that the only published information for >90% of CITES-listed species related to taxonomy and distribution (South African National Biodiversity Institute, unpublished data).

Table 2
Summary of the biological and harvesting information included in the case studies. We excluded five out of the 60 case studies from our analysis because they did not explicitly outline NDF formulation for particular taxa. See the text for details of how this table was compiled.

	Trees	Perennials	Succulents and cycads	Geophytes and epiphytes	Mammals	Birds	Reptiles and amphibians	Fishes	Aquatic invertebrates	All
Basic biological information										
Percentage that had information on ...										
Distribution	100	100	100	100	100	100	100	100	100	100
Trends in distribution	75	50	71	20	50	80	33	20	0	47
Habitat	100	100	100	100	100	100	100	100	100	100
Life history	100	100	86	100	100	60	100	100	100	96
Abundance	88	67	100	20	100	100	50	60	60	75
Trends in abundance	100	100	86	80	63	100	67	100	100	87
Abundance/rates of change in demographic or life history classes	88	50	86	0	100	0	67	100	40	64
Role in ecosystem	50	50	100	40	75	80	100	80	80	73
Harvesting and its effects										
Percentage that had information on ...										
Extractive harvesting	75	50	14	100	88	100	83	100	100	76
Non-extractive harvesting	38	50	100	0	13	0	0	20	0	27
Impacts on population	100	50	71	20	63	80	50	100	60	67
Impacts on ecosystem	13	0	0	0	13	0	17	0	20	7
Recovery rate	63	50	57	20	63	0	17	20	60	42
Sustainable harvest level	38	67	0	40	38	0	17	40	80	35
Harvest experiments	13	17	14	0	0	0	17	0	0	7
Making an NDF										
Percentage that ...										
Use biological information	88	67	100	100	100	40	100	100	100	89
Want more biological information	88	67	86	100	38	60	100	100	80	78
Fraction of case studies used	8/9	6/7	7/7	5/7	8/8	5/6	6/6	5/5	5/5	55/60

Lack of other relevant information will inevitably influence the quality of the NDF decisions and our analysis of case studies illustrates that biologists can contribute to improved policy relating to wildlife trade by addressing the questions that emerge from these case studies.

2. Opportunities for future scientific research

Our 10 key research areas (summarized in Table 3) were identified after reviewing the case studies and extensive discussions amongst the authors. In making our recommendations, we adopted the approach of pairing key points with examples. Our examples are selective towards those that best illustrate our points and the relevant case studies rather than the limited primary literature. The intent was to use the workshop and subsequent discussion as a basis for identifying 10 critical research areas.

Table 3
Our 10 key research areas.

1. Research the relationship between information availability and levels of risk involved in making NDFs
2. Provide guidance on how to most effectively implement adaptive management
3. Research the broader impacts of harvesting on populations
4. Advise on how to make NDFs when multiple species, or parts of individuals, are harvested
5. Identify generalizations for making NDFs that apply across groups of taxa
6. Develop case studies
7. Research the taxonomy and population biology of CITES-listed species
8. Research the ecosystem impacts of harvesting
9. Research the evolutionary impacts of harvesting
10. Research enterprises based on the harvesting of CITES-listed species from the wild

2.1. Research the relationship between information availability and levels of risk involved in making NDFs

Intuitively, more vulnerable species, and those traded in greater volumes, will require more information to allow NDFs to be made because the potential risk of detriment to the species is higher. The making of NDFs can therefore be seen as a type of risk analysis: a popular concept at the NDF workshop (CITES, 2010). Future scientific research could analyse these relationships more rigorously and recommend pragmatic strategies for handling different levels of risk under different circumstances. The case studies on African lions in Tanzania (Ikanda, 2008) and leopards in South Africa (Friedmann and Traylor-Holzer, 2008) used notably contrasting approaches to assess detrimental trade for relatively similar species. What are the costs, benefits and levels of risk that result from using relatively simple indicators to make NDFs and under what circumstances does it become advisable to research and develop predictive population models? For example, annual harvest quotas for African lions were estimated using the knowledge of the abundance of the population in each region by regional experts, their assessment of the condition of the animals being shot, and their knowledge of the impacts of quota levels in previous years. For leopards, the authors used a more detailed computational model to assess the effects of different harvesting levels on the long term population dynamics. One benefit of using formal models is that it is possible to identify those aspects of the species biology and harvesting that have the greatest influence on the future dynamics of the species (e.g. through population viability or sensitivity analyses, e.g. see Curtis and Vincent, 2008). Such analyses enable quantification of the relative risks under different exploitation scenarios.

The extensive scientific literature on "wild harvest" (Leader-Williams, 2008) has principally focused on the extractive harvesting of high value commercial species not covered by CITES, such as timber, fisheries and game animals (Ludwig, 2001; Quinn and Collie, 2005). Re-analyses of some of the better studied systems could be used to determine how predictions of population trends, and even NDFs, would have differed if less information had been available, as is the situation for most CITES taxa. Analyses such as this would help to identify details that are critical to making

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NDFs, and could even allow quantification of the costs and benefits of collecting additional biological information.

2.2. Provide guidance on how to most effectively implement adaptive management

A few species, such as Grizzly Bear (*Ursus arctos horribilis*) (Caceres and Fraser, 2008), are subject to well codified adaptive management regimes. Adaptive management is a mechanism to handle risk and uncertainty by setting precautionary harvesting rates based on current information and adjusting harvesting rates and methods in response to new information (such as the impacts of a previous harvest). The workshop concluded that for the majority of species, where codified adaptive management regimes have not been established, harvest levels could still be managed by measuring harvest effort and monitoring impacts (CITES, 2010). Some of the workshop summary reports suggested simple standard protocols for adapting NDFs for different levels of information (CITES, 2010).

The case study of *Galanthus elwesii*, a geophytic plant from Turkey, describes an adaptive management programme that has allowed an annual harvest of millions of wild plants for international trade for over a decade (Yüzbaşioğlu, 2008). However, like many of the case studies, there have been no peer-reviewed scientific studies of this system. Research on adaptive management programs could examine the effectiveness of current and alternative designs, propose new frameworks, and propose effective and pragmatic methods to adapt species management in light of new information. For example, harvests could be restricted by means of time or area closures, the establishment of quotas, or confining the harvest to a less vulnerable stage of the species' life history. Studies could also conduct comprehensive reviews, including of other systems, and recommend ways to improve the accuracy of estimating detrimental harvest levels.

A current trend in ecological research is the adoption of Bayesian methods to formally incorporate uncertainty into the formulation of mathematical models (Ellison, 2004; McCarthy, 2007). These are now commonly developed for commercially important harvested populations and can be used in adaptive species management (Jennings et al., 2001). At least in theory, such models can be continually updated with current information, and can allow probabilities to be placed on the predicted outcomes of different management options. The case studies of the fish *Cheilinus undulatus* in Indonesia (Sadovy and Suharti, 2008) and the Narwhal, *Monodon monoceros*, in Greenland (Witting et al., 2008) give examples of the application of Bayesian models to assist in stock estimations and quota setting. The interactive stock assessment model for *C. undulatus* in Indonesia (Sadovy et al., 2007) is an example of a tool specifically designed to enable users to take account of current levels of knowledge and uncertainty about the biology and harvesting of the species when making estimates of sustainable harvesting levels. At present, such methods are rarely used for CITES-listed taxa. Research that adapts and develops new models with the intention of advising in adaptive management programmes will not only benefit those making NDFs for specific taxa but can be adapted for other taxa, and may also allow a critical assessment of the benefits of Bayesian modelling, or other modelling approaches, for sustainable harvest management. For example, the stock assessment tool for *C. undulatus* has been designed such that individual countries can adapt the model to their own circumstances.

2.3. Research the broader impacts of harvesting on populations

Few of the case studies cite actual harvesting experiments for the purposes of gaining insights to help formulate NDFs (Table 2), although such "perturbation experiments" are commonly used by ecologists to reveal insights into how certain factors influence the dynamics of ecological systems. One example where harvesting experiments had been conducted is of the non-extractively harvested populations of the medicinal plant *Nardostachys grandiflora* (Larsen and Olsen, 2008). Ghimire et al. (2008, cited by Larsen and Olsen (2008)) compared the dynamics of populations of *N. grandiflora* that had been experimentally subjected to different harvest rates. They found significant differences in the rate of recovery in different habitats and, as a result, estimated different sustainable harvesting rates and rotations for each habitat. Real time studies of the effects of population manipulations such as these may be prohibitively expensive to conduct for many CITES-listed species but a cheaper alternative would be to compare already-harvested with unharvested populations (e.g. Acosta, 2006).

A number of the case studies highlight that over-exploitation for international trade is just one of several anthropogenic factors potentially influencing the biological status of the wild taxa in question. There may be local trade and additional threats, such as habitat loss, pollution, invasive species and climate change, which could interact with the effects of harvesting. When assessing detriment therefore, the impacts of harvesting for international trade may need to be considered in relation to the impacts of other factors present. For example, the case study of the Narwhal, *M. monoceros*, in Greenland (Witting et al., 2008) found that they were unable to recommend an NDF because there was already sufficient evidence that harvests at a national level were unsustainable.

The process of exploitation can also have impacts that are not reflected in trade data such as "hidden mortalities". The case study of seahorses (Foster, 2008) highlights that the largest source of seahorses for international trade is a result of bycatch from fishing and not targeted harvest. In such cases, only a fraction of the individuals removed will enter international trade. Moreover, the harvesting methods can damage the seahorse habitats, probably reducing the potential for population recovery (Curtis et al., 2007; Foster, 2008). More generally, the case studies highlight that the specific taxa (or parts of taxa) that eventually appear in international trade may represent just one part of a more complex (and interacting) network of anthropogenic effects on CITES-listed taxa. Ecologists have developed, in a number of cases, an extensive knowledge of the relative roles of different natural factors (e.g. climatic conditions, life history traits) and their interactions in influencing the dynamics of wild populations. Some of the complex harvesting scenarios outlined in the case studies present an analogous challenge: to quantify the relative roles of these different threats to harvested populations. They also add an additional incentive: any novel findings are likely to be of practical benefit to NDF makers.

2.4. Advise on how to make NDFs when multiple species, or parts of individuals, are harvested

Several of the case studies highlight the difficulties of making NDFs when the species being regulated belong to a large group of seemingly very similar taxa (to the untrained, or even the trained, eye), including orchids (Mites, 2008), seahorses (Foster, 2008) and corals (Atkinson et al., 2008; Bruckner et al., 2008; Suharsano and Bruckner, 2008). In such cases multiple CITES-listed taxa may be harvested and/or traded together so that the NDF needs to consider wider impacts. Research could be conducted to identify efficient ways of determining detriment in such cases.

Another detail that makes NDFs difficult for corals is the problem of defining units to actually measure when monitoring abundance in the wild, or the quantities that are harvested (Atkinson et al., 2008). Scientific studies could identify measurable parameters that most accurately reflect a detrimental impact on species or ecosystems.

Around one third of the case studies involve non-extractive harvesting (Table 2), with the majority being plant taxa, and studies on the effects of different types of non-extractive harvesting could provide useful information for such systems. In general, the impacts of non-extractive harvesting on populations have received less research attention. The case study of the Cycad, *Cycas circinalis*, reports data on the effects of harvesting different plant parts on the size structure of the populations (Varghese and Ticktin, 2008). More detailed investigations of precisely how different types of harvest affect populations, and their interacting affects, would be informative to those assessing detriment.

2.5. Identify generalizations for making NDFs that apply across groups of taxa

The extent to which effects of harvesting one species also apply to other similar species is an area of significant uncertainty for many taxa. Reviews of the effects of harvesting on a wide range of fish (Reynolds et al., 2001) and mammal (Purvis, 2001) populations illustrate that such comparisons can be informative and similar surveys for other CITES-listed species groups would be useful. For example, the succulents and cycads working group deliberately selected long lived perennial species for their case studies partly because they wanted to investigate if there was consensus in the biological factors deemed to be critically important when formulating NDFs. In their summary they report "remarkable consistency" in the factors likely to be associated with detrimental harvesting (CITES, 2008). For example, the extractive harvesting of whole adults was considered to be highly threatening to the survival of the populations.

2.6. Develop case studies

Scientists rarely have access to the background information and methods used for actual NDFs because most Parties to CITES do not make their NDF decision making process public. However, much of the information used by Parties may already exist in the public domain, making it possible for external scientists to comment on and supplement this information. Such analyses need to consider discrepancies between different data sources, for example the exact number of specimens in international trade, which can vary significantly between different sources (Blundell and Maschia, 2005; Chen et al., 2009; Nijman and Shepherd, 2010).

A number of scientific studies to date have advised or commented on the CITES NDF making process for specific taxa (e.g. Blundell, 2007; Castello and Stewart, 2010; Grogan and Schulze, 2008). The workshop case studies highlight that scientists can produce an even larger number and wider variety of critically-reviewed case studies. The long term development of a body of further case studies could lead to the identification and refinement of practical advice about making NDFs and could also lead to a more widespread understanding about effective NDF making practices. This could be of particular benefit as many of the exports of specimens of CITES species are made by biodiversity rich countries with relatively limited resources for CITES implementation.

2.7. Research the taxonomy and population biology of CITES-listed species

For some CITES-listed taxa, there remains great uncertainty about even the most basic biological details, such as taxonomic identity, distribution and life history characteristics. For example the case study of the tropical freshwater fish *Arapaima gigas* highlighted that the species listed on CITES may actually represent four biologically distinct species (Castello and Stewart, 2010). Similarly, there also remains uncertainty about the identity and ecology of species listed at the genus or family level, such as seahorses (Foster, 2008). These provide opportunities for scientists, such as taxonomists, to become involved in more traditional information gathering about the biology of poorly studied species and would provide valuable baseline information for SAs.

One way of acquiring NDF relevant information indirectly is if research into CITES-listed species can be justified on the basis of addressing current scientific questions. Population ecology is one area of research in which novel scientific findings could be made using CITES-listed species as study organisms. For example, studies of density-dependence in determining the dynamics of populations (Ratikainen et al., 2008; Sibly et al., 2005) would generate information that would inform management practices. Much of fisheries research has been dominated by concepts for identifying appropriate sustainable harvest strategies (e.g. maximum sustainable yield) that fundamentally depend on the assumption of a density-dependent population dynamics (Quinn and Collie, 2005).

Understanding the importance of different life history stages to the dynamics of populations is another major research area, although field studies are limited because they normally require a considerable amount of research effort (e.g. Ozgul et al., 2009). CITES-listed taxa could provide a valuable justification for studying populations at this level of detail. For example the case study of *Dioon edule* populations in Mexico (Vovides, 2008) reports on how findings from scientific studies of the demographic parameters of the populations are used in the making of NDFs and notes that further studies are required to refine those estimates.

The study of long-term datasets has also provided valuable insights into the natural dynamics of populations (e.g. Hsieh et al., 2006). Long term monitoring programmes for the purposes of adaptive harvest management of CITES-listed taxa could provide a practical justification for the long term monitoring, experimentation, and data collection. For example, the case study for *Gonystylus bancanus* in Malaysia (Lian Chua, 2008) reports that populations are censused regularly, and under different harvesting treatments. Data such as these could already be a useful resource for ecological studies and, if maintained, could become a valuable long-term dataset.

2.8. Research the ecosystem impacts of harvesting

Scientific Authorities are also required to consider the effect of harvesting on the species' role in its ecosystem when formulating NDFs, although our review of case studies suggests that such information is rarely known (Table 2). The link between species and ecosystem functions is a dynamic area of research where testing concepts such as diversity–stability relationships (Creed et al., 2009; Kirwan et al., 2009), keystone species (Lovari et al., 2009; Murdoch et al., 2009), ecosystem engineers (Beck et al., 2010), and the impact of species losses (extinctions) (Lyons and Schwartz, 2001; Petchey, 2000) and additions (invasions) (Miehls et al., 2009) on ecosystem function continue to generate considerable research interest. Including CITES-listed species in such research can meet the dual objectives of advancing ecological theory and providing valuable information for SAs.

A related but more applied area of research is the impact of harvesting practices on other species or entire ecosystems. For example, the impacts of harvesting were considered important for all of the epiphytic orchids case studies (Khayota, 2008; Mites, 2008; Sripotar, 2008) because harvesting methods can result in varying degrees of damage to the host plant or the ecosystem. In contrast, the case study of the Mexican Cycad, *D. edule*, provides an example where management of harvesting can have a positive impact on the ecosystem (Vovides, 2008). The management plan for *D. edule* allows villagers to propagate and sell plants from wild collected seed (according to a quota) on condition that they conserve the wild habitat and plant some of the propagated seedlings back into the wild.

2.9. Research the evolutionary impacts of harvesting

Selective harvesting can have a variety of effects on the future evolution of the harvested species and connected species in the ecosystem (Allendorf et al., 2008; Coltman et al., 2003; Law, 2001). This has become an important issue in fisheries management (Andersen and Brander, 2009). CITES-listed species offer a wide variety of systems in which the effects of harvesting on species evolution could be studied and could generate NDF relevant information. For example, the case study of CITES-listed seahorses (Foster, 2008) recommends that, in the absence of even basic data on most CITES-listed species, a minimum size limit for all species harvested is a sensible minimum measure (although see Curtis and Vincent, 2008). What impact would the same size-based harvesting limit have on the evolution of the different seahorse species? In contrast to seahorses, more biological information appears to be known about the Mahogany populations of South America (Mejia et al., 2008), although the relatively long generation times mean that studying the evolutionary consequences of selective harvesting in the field is likely to be unfeasible. The selective logging of Mahogany has been shown to significantly reduce the genetic diversity of the species (Andre et al., 2008). Theoretical modelling is probably necessary to explore the potential consequences of the loss of such diversity.

2.10. Research enterprises based on the harvesting of CITES-listed species from the wild

International trade in CITES-listed taxa can involve a variety of stakeholders including local communities, government authorities and national and multinational companies. However, few peer reviewed studies have been conducted that investigate the relative benefits to the different stakeholders involved in the trade, or have researched the relative costs and benefits of alternatives to the established trade structure. The case study of Vicuña in Peru (Hoces Roque, 2008), details how changes in the harvest management have the potential to improve both the conservation of the wild resources and the financial returns for local communities.

A 10-year study in Turkey examined an alternative way of supplying a CITES-listed plant species for international trade (Entwhistle et al., 2002), comparing the benefits of harvesting wild plants with harvest of plants derived from wild collected mother stock but planted in local fields. While the project showed that the planted stock could potentially be used to supply bulbs for international trade, it also highlighted a number of technical difficulties that reduced the commercial viability of the method. For example, the returns on the initial planted stock were quite low relative to the initial quantity of material planted in the first year of harvest. Studies such as these could benefit those directly involved in the trade, some of whom often lack the resources to fund such studies, and those wishing to start new sustainable enterprises based on harvesting taxa from the wild (Dickson, 2008; Abensperg-Traun, 2009).

3. Conclusions

Our review of the case studies has shown that the amount and type of biological information used in making NDFs varies considerably but that, generally, the making of NDFs would be easier if there was more information on the taxa. In response to this we have identified ten general areas in which scientific research could contribute to the NDF making process (Table 3). There is also scope for methodological studies. What methods work best at assessing detriment, given different levels of time and resources available to spend on making a decision? Studies focussed on these aspects for CITES-listed species would benefit those making NDFs for target species and improve the knowledge base for the management of wildlife trade. Research collaborations between scientists, Scientific Authorities and local communities are probably the most effective way to carry out such studies. This would increase the chances that they meet the combined goals of improving sustainable resource management and providing new scientific insights.

One of the key aims of scientific research is to generate theory, which should result in a more predictive understanding of the systems being studied. The making of NDFs relies on theories, knowledge, methods, and techniques that can be applied to the management and regulation of species in trade and therefore requires the ongoing research to reach a point where such applications are possible while contributing to the conservation and sustainable use of diminishing biodiversity worldwide.

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