Plenary Presentation 3

HARVESTING THEORY AND ITS RELEVANCE TO MAKING NON-DETRIMENT FINDINGS

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Introduction

Determining when international trade is likely to prove detrimental to the survival of species is an essential step to achieving the aims of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Indeed, the overall success of the Convention rides on ensuring that species are not transferred from Appendix II to Appendix I. In turn, this requires that non-detriment findings are made effectively, in order to prevent species from being uplifted from a position where international commercial trade is effectively regulated to one where it is banned (Wijnstekers 2003). Therefore, it is very important that those in Scientific Authorities responsible for implementing this key step understand the theoretical basis for making non-detriment findings (Resolution Conf. 10.3).

This paper has the overall goal of examining some very simple principles of harvesting theory to ensure that less advanced Scientific Authorities increasingly enhance their capacity to make effective non-detriment findings. In order to achieve its goal, this paper has the following specific objectives:

- to examine the theoretical differences behind approaches to harvesting that do, and do not, remove individuals from the wild population;
- to briefly consider how harvesting theory and the consequent definitions of over-utilization both allow the non-detriment finding to be applied to well-studied species traded internationally;
- for such well-studied species, to highlight the need for further consideration of impacts of harvesting for trade in relation to the role of the species in the ecosystem, genetic diversity and behaviour;
- by contrast, to recognise that most harvested species and populations are currently poorly monitored, if monitored at all, and therefore to discuss how to set some basic benchmarks such that ongoing harvests can be managed adaptively; and,
- to outline the importance of establishing basic facts and an adequate monitoring system for a programme of adaptive management.

Given there have been relatively few theoretical advances that help support easily achieved improvements to the making of non-detriment findings, this paper is based around the core sections of an earlier paper presented in the Guidance for CITES Scientific Authorities that introduced the so-called ‘IUCN checklist’ (see Leader-Williams 2002). Put another way, this paper is not addressed to those with great knowledge of harvesting theory and extensive data sets on particular harvested species, upon which non-detriment findings can be most easily made. Rather it is addressed to those seeking to understand some of the first principles of harvesting, and how this might be applied to developing the basic capacity to make non-detriment findings, particularly of the many species and populations subject to less well studied harvests.

Effects of different harvesting regimes

Background to harvesting

Man has harvested wild species of animals and plants since time immemorial. Nevertheless, trade in wildlife and its products makes many conservationists nervous, because over-harvesting for monetary profit has so often over-ridden biological concerns (Caughley & Gunn 1996, Freese 1997, Milner-Gulland & Mace 1998, Hutton & Leader-Williams 2003, Milner-Gulland & Rowcliffe 2007). Hence, there are many examples of collapse in trade and/or stocks, particularly of large-bodied, long-lived species of terrestrial and aquatic organisms such as trees, fish, mammals and birds, whose relatively slow rate of reproduction is less than the rate at which interest can be earned on money placed in the bank through liquidating the stock (Clark 1990). A few examples of stock declines are cited below, some of which are for CITES-listed taxa:

- trade in monk seal *Monarchus* spp, sea lion *Zalophus* spp, and fur seal *Arctocephalus* spp;
- the Southern Ocean whaling industry;
- fishing industries for Tuna *Thunnus* spp, Atlantic cod *Gadus morhua* and European eel *Anguilla anguilla*;
- illegal harvesting of Sumatran *Dicerorhinus sumatrensis* and black rhinos *Diceros bicornis*;
- harvesting of Central American mahoganies *Swietenia humilis,* ramin *Gonystylus* spp and agarwoods *Aquilaria* spp; and,
- pet trade in Spix Macaw *Cyanopsitta spixii* and other psittacines.

At the same time, protection of species from trade makes many other conservationists nervous (Hutton & Leader-Williams 2003). Many conservationists argue that sustainable and well-regulated harvesting can generate profits that should strengthen the incentives for terrestrial, freshwater and near shore conservation (Anon. 2008). Among the most often quoted examples of sustainable harvesting having a positive impact on the status of species, or populations of those species, and most if which are CITES-listed taxa are:

- ranching of crocodilians Order Crocodylia;
- hunting of leopards *Panthera pardus*;
- live sale and hunting of southern white rhinos *Ceratotherium simum*;
- trophy hunting of markhor*, Capra falconeri*;

Although these examples of positive success are relatively few, many would also argue that continued consumptive use has done less to impoverish overall biodiversity than converting land to other forms of use where there is no incentive for conservation, such as with clear cutting of forests or cattle grazing of native grasslands. For example, many more known species are threatened by habitat loss than are threatened by international trade (IUCN 2008). Hence, the different rates of loss of taxa to harvesting and to other other threats also need to be considered by proponents and opponents in the “use it or lose it” debate, as well as positive successes (Freese 1997).

Types of harvesting regime

There are two main approaches to harvesting, the first where the individual remains in the wild population, and the second where the individual is removed from the wild population. This distinction is important, because each approach is underlain by different theoretical and practical implications.

The individual remains in the wild population:

Numerous examples exist of actual or possible harvesting strategies where the individual remains alive **and reproducing** in the wild population, some of which are for CITES-listed taxa:

- down collected from nests of eider ducks *Somateria* spp;
- birds’ nests collected from swiftlets *Collocalia* spp;
- wool sheared from vicuña *Vicugna vicugna*;
- the collection of hair shed by muskox *Ovibos moschatus*;
- horn that could be taken from farmed white rhinos *Ceratotherium simum*;
- the collection of plant parts such as of Devil’s claw *Harpagophytum* spp; and,
- the pollarding and coppicing of many species of tree.

For animals, a harvest of this kind may result in some impact to the population, for example, through capture or disturbance. The productivity of such harvests is generally highest when populations are **at their largest size** or **maximum carrying capacity**. However, there is little theoretical basis to deciding whether or not to harvest and upon appropriate quotas. The decision of whether to harvest for animals, for example vicuña wool (but see Bonacic et al. 2006), or not to harvest, for example white rhino horn, and of appropriate quota levels, is largely based on the likely success of imposing trade controls and/or the effects of allowing a legal trade upon other related species and populations. Consequently, should specimens of such species be in international trade, there should be little difficulty in making an NDF.

For plants, by contrast, there may be greater concern over the levels of offtake of harvests that possibly intend to leave the individual alive and reproducing in the wild population. For example, the removal of too much of certain products such as roots, bark or leaves, can prevent the individual from investing in reproduction or even dying. Examples include excessive removal of bark from *Prunus africana*, and of roots from ginseng and Devil's claw (Anon. 2004; Ticktin 2004). In such cases, harvests may need to be considered under the framework below.

The individual does not remain in the wild population:
The other more widespread approach to harvesting is where the individual does not remain alive and able to reproduce in the wild population, either because it is killed or is removed live. There are many, many examples of harvesting by this route, and include the following:

- hunting and cropping in their various forms, whether for sport, trophies, food, medicine, or other animal products;
- fishing in its different forms, whether for sport, food or medicines, or other fish products;
- cutting and collection of timber that does not pollard or coppice, and cutting or collection of other plants, in their various forms, whether for food, medicine, building materials or other products;
- live capture of animals in its various forms, whether for farms and ranches, for zoos, aquaria or the pet trade; and live removal of plants for cultivation; and,
- by-catch, where the species itself is not targeted, but is removed from the wild during harvesting of other species.

In contrast to the approach where an individual remains alive and reproducing in the wild population, a strong theoretical basis underlies the approach to harvesting where the live individual does not remain in the wild population.

Harvesting theory for removing individuals

Harvesting models

Several different models, of varying degrees of complexity, are available to underpin the theory of harvesting as it applies to removal of individuals from a wild population (for details see Clark 1976, 1990, Caughley 1977, Milner-Gulland & Mace 1998; Caughley & Sinclair 1994; Sutherland 2000; Milner-Gulland & Rowcliffe 2007, see also fisheries software ARTFISH). Put simply, sustainable use seeks to remove individuals at the rate at which the population would otherwise increase (Caughley & Sinclair 1994), or as the Convention on Biological Diversity defines use that is sustainable in Article 2: *use **in a way** and **at a rate** that does not lead to the long-term decline of biodiversity, thereby maintaining its potential to meet the needs and aspirations of future generations*.

One of the simplest harvesting models for species or populations that are exploited by removing individuals from the population is the logistic model (Box 1), which suggests that:

- the birth rate will balance the death rate in a population at carrying capacity, such that population does not grow and there are no surplus individuals to remove;
- if populations are reduced in numbers to below carrying capacity, they tend to increase;
- generally, the highest sustainable productivity comes when populations are **below their largest size** or **maximum carrying capacity**;
- the biologically optimal strategy of harvesting is to lower the density to the point at which the population achieves maximum productivity, and then to harvest at the same rate as the population reproduces;
- such harvesting **always** reduces the density of a species, and numbers will decline during the first few years of a harvesting operation, but
- this initial decline does **not** mean that the species is being overutilised.

Decisions on how much to harvest are ultimately limited by the life history of the harvested species that, in turn, provide upper limits to their potential productivity. Equally, the implementation of harvest limits is affected by the demand for the product (indicated by price) and the costs involved in harvesting. For legal harvests, the costs involved are indicated by harvester effort, availability of alternative sources of income and so on; and for illegal harvests the chances of interdiction and associated penalties. To incorporate these different factors, bio-economic models have been developed that incorporate economic aspects of harvesting. Given that a harvester's decisions on how much to take will be affected by the price that obtains and the level of regulation, these bioeconomic models aim to predict how increasing or decreasing payoffs from the harvest can affect the amount harvested. For example, as a product becomes more scarce, its price and thus the incentive to harvest may increase. Equally, if regulation is efficient because the chances of interdiction and sentencing penalties are high for illegal harvesters, this may counteract the effects of increased price. In contrast, for poorly regulated systems or systems where both demand and supply are inelastic then biological sustainability may be compromised (Milner-Gulland & Rowcliffe 2007).

Regulating harvests

All harvesting theory refers to the idea of maximum sustained yield (MSY). Theoretically, MSY is the largest harvest that can be taken from a population indefinitely, without driving the population towards extinction (Box 1). The manager may calculate or arrive at estimates of MSY in two different ways:

- in theory, MSY may be calculated directly in data-rich situations, but most often the biological information necessary for such a calculation is not available;
- in reality, MSY is more often arrived at through the trial and error or adaptive management approach, and this has much to recommend it.

Both these methods of calculating or arriving at MSY result in a relatively fixed yield or constant harvest. Administrators prefer the option of harvesting a constant number, because it allows a fixed quota to be set each year. Such fixed numerical quotas are easy: to visualize; to justify to officials; to share between resource users; and to report to national or international bodies. However, this approach has a number of biological disadvantages, including not taking account of year-to-year changes in population size and not limiting harvesting effort to reach allowed quotas (Box 2).

Alternative approaches to managing harvesting include either limiting harvesting effort or taking a constant proportion of the population (Box 2). Both these approaches to harvest regulation can be much safer biologically than setting a constant numerical harvest, because harvests are self-correcting as a population changes in size. Unfortunately, neither approach produces a fixed yield. Instead, the yield is likely to vary from year to year. Hence, the approach of regulating harvesting effort, which has the advantage of not requiring information on population size (Box 2), has the drawback that most administrators responsible for harvests will be nervous because they no longer have direct control over the size of the actual yield. Furthermore, regulating harvest effort is likely to prove difficult within the context of CITES, where relatively fixed numerical quotas are easier for Parties to understand, approve, report and regulate. Equally, the approach of harvesting a constant proportion of the population requires accurate information on population size, which is often not available in the context of most species traded under CITES.

Complications of harvesting

Despite the underlying biological theory, most population harvesting is a highly practical affair. Either the resource users take:

- an arbitrary harvest from poorly monitored populations each year, or
- as many as they can get with the time and equipment available. This pragmatic approach sometimes results in a sustained yield, sometimes in over-utilization. For example:
- yields taken by recreational/sport/tourist hunters, the harvest being controlled by a government department, are usually inefficient SY, the yield being conservative in terms of overall population

number, but perhaps not in terms of behaviour or genetic heterozygosity (Rowe & Hutchings, 2003; Coltman et al. 2003; Whitmore et al. 2004; Allendorf et al. 2008).

Given the complications of harvesting, for those species and populations where harvests may not be so conservative, the key step in moving towards making an NDF is determine when over-utilization is occurring.

What is over-utilization?

The theory of harvesting outlined above suggests several ways that, under ideal and data-rich conditions, over-utilisation detrimental to the survival of a species may be detected and defined (Caughley & Sinclair 1994).

What are the indications of over-utilization?

Over-utilization may be indicated at a gross scale in several ways:

- there is a justifiable presumption of over-utilization for a harvest where population data are available, and that population is below half its unharvested density and is continuing to decline in an unmanaged manner under harvesting;
- sometimes harvest can be estimated reasonably accurately, whereas population size is known only within very wide limits, if at all. Nonetheless, the sheer magnitude of the harvest may be such that it can confidently be declared above the MSY for any plausible population size. As an example, comparing very crude estimates of African elephant numbers with the volumes of ivory entering the trade in the 1980s suggested that elephants were being harvested above their MSY in many areas of Africa (Caughley et al. 1990);
- sometimes enough is known about the size and life histories of the population to show that harvest is above the MSY, of which many examples derive from the literature on whaling (Clark 1990);
- A number of models have been developed which aim to compare theoretical productivity with estimated levels of harvest and thus to provide indicators of whether harvests are likely to be unsustainable (see Table 13.1 in Sutherland 2000).
- There are many other indicators that can be monitored with more or less success to generate data on population trends, such as comparisons of the following measures taken from the source population and the harvest: sex ratios; age and sex structures over time; size of harvested individuals over time; as well as measures of catch per unit effort, and trends in numbers traded. In addition, measures that incorporate socio-economic factors can also point towards likely sustainability or otherwise, for example: trends in price; trends in alternative livelihood options; changes in infrastructure development, habitat destruction and human migration (see for example Table 4.1 in Milner-Gulland & Rowcliffe 2007).

How can over-utilization be defined?

On the basis of his considerations of underlying theory, Caughley (1992) formulated three possible definitions of over-utilization as follows:

- when the number harvested each year exceeds the maximum sustained yield of the species; or
- when the percentage harvested each year exceeds the intrinsic rate of increase of the species; or
- when the harvesting reduces the species to a level at which it is vulnerable to other influences upon its survival.

This forms a very useful basis on which to move forward for relatively well known species groups such as elephants or whales. Nevertheless, problems still remain for less well-known groups if no estimates of population size or of life history variables are available against which to set harvest rates. For example:

- how does the harvest of several hundred thousand snakes per annum from a rattlesnake drive relate to the size or rate of increase of the snake population; or
- how does the export of several thousand finches per year for the live bird trade relate to the finch population?

Given that over-harvest can be difficult to detect and to reverse, precautionary harvest levels should be set initially to guard against over-harvest, to ensure that effective population size, genetic and behavioural diversity and the species role in its ecosystem are maintained. Depending on body size, precautionary MSYs should be set at 80-90% of *K* for large bodied species, and 60-70% of *K* for medium bodied species, rather than close to the theoretical maximum of 50% of *K* (Bodmer & Robinson 2004).

Adaptive management

Adaptive management, a concept formalized from the process of trial and error, has proven a useful approach to the paucity of data that often surrounds issues of harvesting less well-known species groups. Even for species where some basic facts of biology and ecology such as population size or maximum rate of increase are known, adaptive management is a crucial concept because:

- ecological systems are very complex and great uncertainties surround consequences of the use of those systems, and of the consequences of environmental, social and economic changes; and,
- management itself must be sustainable, and able to adapt to changing conditions.

A system of adaptive management reviews decisions and procedures and uses the lessons learned to adjust the management system. The central component of effective adaptive management is the monitoring system that is incorporated to evaluate management activities. Hence, an act of management, such as harvesting, is designed as a trial, the outcome of which can be assessed scientifically and improved upon where necessary. Therefore, the paper now move to some practical considerations of both a biological and an anthropogenic nature, before describing a basic monitoring system that ensures the establishment of an effective system of adaptive management.

Practical needs for determining if harvests are detrimental

International trade as one of multiple impacts upon a population

The harvesting of specimens for export is only one of a range of impacts and threats that face different species. Scientific Authorities need to be aware of, and take account of, these other impacts, which range from those of a more biological nature, to those that are related to different forms of use.

Intrinsic and extrinsic factors that affect extinction risk:

Both intrinsic and extrinsic factors can affect extinction risk, and such factors are particularly important in small populations (Mace & Lande 1991, Mace et al. 2008). Intrinsic factors include: population dynamics and life history trajectories, such as age structure and variation in rates of birth and death rates; population characteristics, such as genetic variability and dispersal patterns; and, patterns of distribution such as restricted ranges and numbers of sub-populations. Extrinsic factors include patterns and rates of environmental variability, habitat quality and availability, interactions with other species, catastrophes and contagious diseases. In an ideal world, knowledge of these impacts would allow harvests to be modified to improve the chances of species survival. Nevertheless, in reality many harvests are conducted in the absence of full knowledge, and many even lack monitoring that aims to keep an adaptive harvest within precautionary limits. Nevertheless, threats can be synergistic in nature and can cumulatively affect extinction risk. While the interactions between intrinsic and extrinsic factors are increasingly well understood (see Cardillo et al. 2005), more effort will be required to monitor the effects of climate change and its association with emerging infectious diseases, which are of increasing concern to conservationists (Brook et al. 2008).

Harvesting impacts:

Species may be harvested for a range of uses other than for the international trade that comes under the purview of CITES. These uses may include local or domestic hunting, or capture of species for sport, trophies, food, medicine or other animal products, carried out with or without legal sanction. In addition, consideration must be given to the scale of any international trade that is carried out illegally. Furthermore, there may be additional losses to the population that occur before export, for example due to unrecovered fatal wounding of hunted animals, or capture, post-capture or transport mortality of live-caught animals. At its extreme, international trade that is non-detrimental to the survival of a particular species must avoid reducing, either directly or indirectly in association with a biological impact or another type of harvest, the total population of that species to a size, structure, genetic diversity or number of sub-populations that is in any greater risk of extinction than it is already. However, there is an important practical implication of this definition. International trade in threatened species need not necessarily be precluded, providing it can be shown that it at least contributes to the lessening of threats such as habitat conversion or pest control that are occurring anyway. One classic example here is the crocodilians, where ranching has led to improved status of several species as opposed to continued and increasing threats causing further declines in status. Two other examples include the southern white rhino and local markhor populations whose status has been greatly improved by limited trophy hunting.

Species characteristics and type of harvesting

Species that are harvested display a wide range of life history patterns. Equally, different types of harvesting may target different segments and proportions of the population. These factors can in turn interact in determining whether international trade might be detrimental to the survival of the species.

Species characteristics:

Two important ecological characteristics of individual species need to be considered: the concept of fast and slow life history strategies, formerly known as *r* and *K* selection, respectively, and the principles underlying the trophic structure within ecological communities (see for example Begon, Harper & Townsend 1996; Garcia et al. 2008).

In very general terms, species of large body size within particular taxonomic groups tend to grow slowly and have a high age of sexual maturity, have a low reproductive rate, produce few young and invest heavily in their survival, have a low rate of adult mortality and be selected to survive at carrying capacity, *K*, in relatively stable environments. Among mammals, the classic example is an elephant. In contrast, species of small body size within particular taxonomic groups tend to have a low age of sexual maturity and a high reproductive rate, produce more young and invest less in their survival, have a high rate of adult mortality and be selected to survive and reproduce rapidly, with a high *r*, in more variable environments. In general, species with larger body sizes, smaller ranges, and smaller populations numbers tend to be more extinction prone. This generalization of slow and fast species, or *r* and *K* selected species, like all dichotomies, is an oversimplification. However, it provides a useful framework in which to consider the biologically optimal strategies by which to harvest particular species. Energy is lost each time it is converted through different trophic layers of an ecological community. Hence, there is a lower biomass of carnivores than there is of herbivores, while in turn there is a lower biomass of herbivores than there is of primary producers. This generalization also provides a useful framework in which to consider proposed quotas. There should be fewer lions than buffaloes on an African hunting quota, and fewer raptors than finches on a live bird quota, without raising suspicions that trade might be detrimental to the survival of those species in higher trophic layers.

Harvesting characteristics:

Different types of harvesting target different segments and quantities of the population, as the following examples highlight:

- legalized trophy hunting specifically targets small numbers of prime males, usually well below MSY, while unregulated meat hunters harvest age and sex classes more indiscriminately and in larger numbers, and often close to or above MSY;
- live capture of birds and reptiles for the commercial pet trade also targets sub-adult and adult age and sex classes relatively indiscriminately and in large numbers, while live capture of animals for zoos, terraria and aquaria is generally more selective and of lower volume;
- a crocodilian ranching operation specifically targets the harvest of eggs and juveniles, which otherwise experience very high levels of mortality of around 98% annually. In contrast, the harvest of adult crocodilians, which are generally long-lived, slow to reach sexual maturity and experience low mortality

> of some 5–6% annually, for skins and/or pest control is generally above MSY and can result in a population decline.

The crocodilian example shows a very clear recognition of the need to combine biological characteristics of the species and the approach taken to harvesting in a manner that is least detrimental to the survival of the species concerned. In contrast, any high volume and indiscriminate harvesting of a large-bodied predator would give grave cause for concern, as MSY could easily be exceeded, while a high volume trade in a small bodied and rapidly reproducing herbivore or granivore would give less cause for concern.

Role in the ecosystem

Knowledge of the role of species in their ecosystem is important and should also be obtained where possible, and considered in determining harvesting levels. For example, predators may play a role in regulating the population sizes of their prey species, so removal of too great a number of predators could results in imbalances to the ecosystem, for example the removal of too many snakes has been associated with rat plagues. Similarly, fruit bats are important pollinators, but also much in demand for bushmeat and for trade. Worldwide loss of pollinators is likely to have serious consequences for natural and agricultural productivity. Role in the ecosystem may also be important indirectly, through the effects of harvesting of the target species on a by-catch species. Reviews of general literature can help determine whether the species is likely to be a keystone species; predator; prey; pollinator, pest, and so on.

Establishing a monitoring programme in an exporting country

The theory of harvesting already outlined has been developed from well-monitored fishing and whaling operations, and added to with examples from well known terrestrial mammals. At present, monitoring of both populations and of capture effort in many exporting countries is poor or non-existent for many species harvested for international trade, particularly for those species that are hard to census directly. So, the basic requirements for ensuring that utilization is not detrimental to survival are not being met at present for many harvested species. Thus, there is a yawning gap in both practice and understanding between the principles established through harvesting theory, and the practical management of many harvesting operations, including for international trade. Given that much harvesting will continue anyway, whether or not attempts are made to outlaw it through domestic or international measures, and given the concept of adaptive management, it is incumbent upon resource managers to review harvesting operations under their management. Thus, Resolution Conf. 10.3 recommends that *countries of export base their regimes of harvest management on the scientific review of available information on the population status, distribution, population trend, harvest and other biological and ecological factors, as appropriate, and trade information relating to the species concerned*.

In order to establish the context of their international trade, and any subsequent monitoring programme, the first step for any exporting country is to establish an appropriate policy and legislative regime (see CITES work on development of national wildlife trade policies). The subsequent implementation and success of any harvesting programme is first determined by defining the objectives of such programmes. Management regimes and trade controls for particular species must be part of a larger overall government policy for wildlife conservation and utilization. Governments should determine their priorities, for example, habitat and/or species conservation, generation of foreign currency, development of employment opportunities, and so on. Once identified, these priorities can provide the foundation of government policy, and the general framework within which to develop management schemes for single species or species groups in international trade.

There are then two main components for a comprehensive monitoring programme, first biological monitoring and second, the monitoring of harvests and export controls (quota, permit and trade-monitoring system). In an ideal world, biological monitoring should precede the monitoring of harvests and export controls. However, harvesting is often the way in to establishing MSY through adaptive management, and this more often precedes the gathering of detailed biological information on the harvested population. Nevertheless, this section will assume an ideal world and will first discuss the requirements of biological monitoring.

Establishing a simple biological monitoring programme:

This first requires the collection of baseline population data, where none previously exists. A practical and sensible methodology would comprise the following:

Assessing suitability of species for different levels of harvest:

- determine the basic biology of the species, and accept that large-bodied species or rare species or food specialists are more at risk of harvest than small-bodied species or generalists; and
- assess the geographic distribution and range of the species, and accept that endemic and localized species are more at risk than widespread, non-endemic species.

Assessing risks of harvest:

- determine the area of available habitat within the range of the harvested species and the proportion that is protected, and assume that those species receiving no effective protection are more at risk of harvest;
- assess extent of other forms of harvesting other than international trade, and accept that those subject to illegal or uncontrolled harvests are more at risk than those subject to long-standing and well-regulated harvests;
- survey the population density in representative parts of the range, and compute the likely upper and lower population levels, coupled with an evaluation of reproductive and recruitment rates;
- based on the above, the calculation of conservative harvest quotas, using the lowest likely population level and taking note of the intended method of harvest, and apportionment of allowable harvests to international trade and other categories.

To make some of the initial assessments, Scientific Authorities can, at the very least, refer to field guides, The World Database of Protected Areas (www.unep-wcmc.org/wcpa), and Red Lists (www.iucnredlist.org) as well as data from FAO Forest and Fishery assessments (www.fao.org), from the CITES databases (www.cites.org) and from the CBD (www.cbd.int/countries), i& good local data are not available. Lists of protected areas show how much of that range is theoretically under protection. Red Lists provide an international assessment of threats to species, however coarse grained these may be for the situation in individual range states. Local data sources might comprise: biologists and anthropologists from local universities who have undertaken studies of distribution and status, or of use; national or regional biodiversity inventories (e.g. Stuart & Adams (1990) for sub-Saharan Africa); government departments of forestry, fisheries, agriculture and environment, who may have figures on rates of habitat conversion, livestock density, pesticide use and pollution; protected area managers, who can assess the proportion of the range or population under effective protection; as well as interviews with hunters and traders (see Jones et al. 2008), and so on.

This initial assessment can be developed into a regular monitoring programme that undertakes annual censuses of density in the same areas of the range as above, using game scouts, local communities, university students, CITES Scientific Authority, and others. This should also be accompanied by the annual monitoring of capture effort, using an index relevant to the system of harvesting, for example hunter days, and regular reviews of distribution and habitat availability. Quotas can be revised as necessary based on information collected through regular monitoring.

Monitoring of harvest and quotas:

Governments of exporting countries should aim to establish an annual harvest for each species harvested for domestic use or export, and allocate that harvest between different resource users according to policy objectives. This will be much easier for the larger mammals. However, even for this group, assessing levels of illegal harvest remains difficult. It may be necessary to develop these levels of harvest with input from qualified scientific experts, depending on the levels of local capacity.

Harvest should be allocated and harvesting effort monitored in a manner that both recognises the importance of maintaining harvests within established limits and that also recognises other possible losses from the population, such as illegal harvest, fatal wounding or capture and transport mortality. In many cases, quotas alone do not provide adequate control of harvests and exports. To be effective, they must be combined with an intEgrated capture and export permit system that is tracked and monitored. Permits must identify permissible harvests of each species for both domestic and international trade.

At the same time as the size of harvest is monitored, the harvest should also be sampled for its age and sex structure. This would entail the weighing, measuring, ageing and sexing of an appropriate proportion of the harvest. For example, every leopard hunted in an export quota in the low hundreds could be weighed and measured, and a tooth be taken for ageing. In contrast, the weight, length and carapace of every tenth tortoise in a quota of several thousand tortoises could provide an adequate sample on which to look for tell-tale signs of exceeding MSY, using the approaches successfully pioneered by fisheries biologists.

Conclusions

The gap between theory and practice in the regulation of harvests remains large for many harvested species in international trade. The theory of harvesting provides a useful starting point that has a firm empirical basis for better known and monitored species. However, for many other harvested species in international trade, the application of theory remains far removed, and the main requirement is to establish simple and practical monitoring systems that allow future regulation of harvests through adaptive management.

Biological systems are inherently complex and affected by unpredictable stochastic events. Therefore, harvesting models that seek to simplify such systems have drawbacks to their use. To achieve biological sustainability, all harvests should consequently seek to be precautionary in their limit, and be set in defined populations where increasingly robust indicators are used, comprising at the least, monitoring of trends in abundance.

Box 1. Details of logistic model

Populations can grow in a logistic fashion, represented by an S-shaped (sigmoidal) curve, until the population reaches its maximum size *K*. The rate of growth is slow initially, increases to its maximum *rm* and slows latterly as *K* is approached. If the population is now harvested at an instantaneous rate to hold the population size constant at any point along the S-shaped curve, the instantaneous harvest rate must equal the instantaneous growth increment. If the logistic equation is substituted, this produces an equation that has the algebraic form of an upwardly convex parabola passing through the origin. The sustained yield (*SY*) is the same as the harvesting increment, and this parabolic equation informs us that:

- *SY* is zero when *N* is zero (i.e. no population, and therefore no yield);
- *SY* is also zero when *N* is set at its maximum unharvested size of *K* (because the realised growth rate when $N = K$ is zero). Thus any harvest from a population of size *K* will decrease the size of the population;
- Between $N = 0$ and $N = K$, the *SY* first rises and then falls;
- The *MSY* (maximum sustained yield) is taken from a population size of $N = 0.5K$ at the instantaneous rate $H = 0.5rm$.

Hence, the logistic model allows MSY to be defined as the harvest that keeps the population at half the carrying capacity. The manager may calculate or arrive at estimates of MSY in two different ways:

- In theory, MSY may be calculated directly from the **size of a population** before harvesting and its **maximum rate of increase**, combined with various other attributes of the species and its environment;
- In reality, population size is often not known prior to or during harvesting, so MSY can seldom be calculated directly.

The approach used most often is to begin harvesting with an annual yield set well below the likely MSY. The population is monitored directly or through indices of abundance to confirm that it is behaving according to prediction, in other words it is not decreasing. After several years, the yield may be cautiously fine-tuned up towards the MSY. This is the trial and error or **adaptive management** approach to estimating MSY.

N.B. It is increasingly recognised that due to the unpredictability of environmental and other stochastic events, harvesters should not aim to achieve MSY, but rather aim for a more precautionary level of harvest.

Box 2. Methods of regulating a harvest

a) Harvesting a constant number

For the administrator, the harvest of a relatively fixed yield, or constant number, is the preferred option as it allows the setting of a fixed quota each year. However, setting a constant number for harvest can, and often does, push a population below the size yielding MSY because:

- environmental variation, such as bad winters or prolonged dry seasons, can cause considerable year to year variations in population size; and,
- it encourages greater harvesting effort or the introduction of improved technology, in other words working more and enjoying it less, as in the case of most fisheries heading for collapse.

Hence, the harvest of a constant number, and any subsequent quotas, should be set at considerably less than MSY.

b) Harvesting with a constant effort

Within limits, a given harvesting effort takes about the same percentage of a population whether it is at high or low density. Regulating by effort thus tracks population size by taking more animals when the population is larger and fewer when it is smaller. Such a safeguard is exactly what is needed when harvesting those species whose numbers fluctuate from year to year (for example, the irregular entry of a strong age class into the population, or irregular climatic changes that are a feature of the life history and ecology of the saiga antelope, *Saiga tartarica*) or whose size is not monitored regularly. The maximum sustainable harvesting effort represents that level of effort that takes a proportion of the population each year equal to the population's maximum rate of increase in that environment. Regulating harvesting with a constant effort may take the form of:

- in the case of a fishery, a limit on the number of boats licensed to harvest a fish stock, a specified type of fishing equipment or a limit on boat-days, or,
- in the case of a hunting area, a limit on the number of recreational hunters licensed to hunt a particular area, a fixed hunting season, or a limit on numbers of hunter days, and so on.

The approach of regulating harvest through a constant effort is biologically more robust than regulating it through a constant number. Among its major advantages are:

- that it needs less fine tuning than constant yield harvesting, and can produce higher yields; and,
- it can be administered without monitoring population size or knowing the relationship between population size and population growth rate.

Among its disadvantages are:

- that it tempts harvesters to use more sophisticated technology to circumvent limits on hunting or fishing days;
- yields vary from year to year, depending on population size; and,
- the resource users may not see a clear relationship between policy and practice.

c) Harvesting a constant proportion of the population

Regulating harvesting by taking a constant proportion of the population has the same underlying theoretical basis of self-correction as harvesting with a constant effort. The optimum sustainable harvesting effort takes a percentage of the population each year approximately equal to half the intrinsic rate of increase. This is not half of the population size before harvesting starts, but half of the much reduced size to which the population is held down by harvesting. The approach of regulating harvesting by taking a constant proportion of the population offers a different mix of advantages and disadvantages to the approach of harvesting with a constant effort. Among the advantages of the former are:

- resource users can see a clear relationship between harvesting a constant proportion of the population and its biological characteristics; and,
- harvesters can use any technology they please, to ensure that harvesting is economically more efficient than constant effort harvesting.

Among its major disadvantages are:

- the population size must be known in order to set the harvest, which may prove a considerable expense for the regulator; and,
- yields will vary from year to year depending on population size.
- yields taken by professional fishermen or full-time hunters, even when harvest is being controlled by a government department or an international convention, are usually too high, the stock being forced down to a level that is uneconomic to harvest. The fishing fleet or hunting gang then moves to a new stock.

Even scientifically sanctioned calculations of sustained yield do not necessarily produce more success in conserving stocks than the pragmatic option, e.g.,

- year-to-year variations in the environment are often not included, and tend to lower the actual sustained yield that can be harvested; and,
- economic considerations are often omitted.

d) regulating a harvest using rules of thumb

When little data are available on population status or productivity of harvested populations, other methods have been used to manage harvests, including imposing a minimum size for harvested specimens or, more recently, for trophy hunting harvesting post-reproductive individuals. These methods also do not allow enforcement through monitoring a fixed number on a quota to be exported, but in theory require enforcement staff to check measurements or other details of the harvested specimen:

- Harvesting individuals greater than a minimum size seeks to ensure that a proportion of the population is able to reproduce before reaching the size at which it is harvested. This method is most useful for taxa that do not display determinate growth. In other words taxa that continue to increase in size after reaching sexual maturity and throughout their life, notably fish and reptiles.

- Harvesting post reproductive individuals aims to ensure that genetic diversity is not lost from the population, by harvesting the “fittest” individual, usually those with the largest trophies, only after they have passed on their genes through reproduction.

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