Biological Conservation 172 (2014) 155–162

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Perspective

Re-defining recovery: A generalized framework for assessing species recovery

Alana Westwood *, Emilie Reuchlin-Hugenholtz, David M. Keith

Department of Biology, Dalhousie University Halifax, Nova Scotia B3H 4R2, Canada

ARTICLE INFO

Article history:
Received 2 October 2013
Received in revised form 13 January 2014
Accepted 22 February 2014
Available online 22 March 2014

Keywords:
Conservation
Protection
Endangered species
Recovery
Species at risk
Policy

ABSTRACT

At present, the concepts of 'recovery' and 'recovered state' are poorly defined and often confused within academic literature and legislation. These definitional inconsistencies result in global ad hoc attempts at recovery and recovery plans that typically exhibit low success rates, and whose outcomes are difficult to evaluate. There is a dire need for an internationally accepted framework to guide the development of plans for the recovery of populations, species, and ecosystems. Such a framework must distinguish between the process of recovery and the end-state of recovered, and implement quantifiable, generalizable guidelines that ensure optimal outcomes. Drawing from established principles in medicine, we introduce a 5-stage classification of recovery: Diagnosis, Treatment, Stabilization, Rehabilitation, and Recovered. Recovery and recovered states should be measured objectively, using population health metrics relevant to the life history of the population, organism, or ecological unit under consideration. These metrics should be used to establish a baseline, set targets for a recovered state, and monitor population health in accordance with the five stages of recovery. This framework could be used to overcome significant problems of unpredictable decision making, definitional inconsistencies, and an inability to measure recovery or learn from failures and successes. The guidelines we propose are intended for adoption by conservation agencies, and provide a quantified, accountable system that could greatly improve the likelihood of populations successfully reaching recovered status.

Contents

1. Introduction . . . 156
   1.1. Recovery in academic literature . . . 156
   1.2. Recovery in legislation . . . 157
   1.3. Recovery in medicine . . . 158
2. The process of population recovery . . . 158
   2.1. Stage 1: Diagnosis . . . 158
   2.2. Stage 2: Treatment . . . 159
   2.3. Stage 3: Stabilization. . . . 159
   2.4. Stage 4: Rehabilitation . . . 159
   2.5. Stage 5: Recovered . . . 160
   2.6. Comparison to existing frameworks . . . 160
3. Conclusion . . . 161
   Acknowledgements . . . 161
   References . . . 161

* Corresponding author. Tel.: +1 902 494 6279; fax: +1 902 494 3736.
E-mail addresses: a.westwood@dal.ca (A. Westwood), ereuchlin@gmail.com (E. Reuchlin-Hugenholtz), keithdm@dal.ca (D.M. Keith).

http://dx.doi.org/10.1016/j.biocon.2014.02.031
0006-3207/

1. Introduction

In principle, species at risk legislation could be used to prevent extinction of populations and species, as well as potentially facilitate their eventual recovery (Coristine and Kerr, 2011). Thorough guidelines exist to guide conservation biologists in assessing extinction risk at international, national, and sub-national levels (e.g. IUCN Species Survival Commission, 2000; COSEWIC, 2011). These guidelines provide a consistent framework for agencies to identify populations at risk, develop recovery plans and, if necessary or possible, execute management actions intended to facilitate recovery. However, there are no comparable guidelines to determine if a population has begun to recover, or is close to reaching a recovered state.

In scientific literature and legislation, definitions of recovery and recovered states are varied, inconsistent, and often inadequate for meeting conservation objectives. It is currently unclear what a 'recovered' population entails in terms of population size, range, viability, and ecological role. Furthermore, though the process of 'recovery' is often confused with an end-state of 'recovered', this distinction has important consequences for both policy and biological outcomes. Three main problems arise from disparate and incongruent definitions in literature and policy:

(1) There is no operational, internationally accepted framework that will guide species recovery after a species is removed from at-risk status. This lack of an *a priori* framework can lead to inconsistent and ad hoc methods when making recovery plans and policy decisions (D'Elia and McCarthy, 2010).
(2) Recovery plans, even within a jurisdiction, can be inconsistent in terms of what constitutes a recovered state, and a function of the time at which the strategy was formed (Elphick et al., 2001).
(3) It is difficult to quantitatively evaluate outcomes of recovery actions given their diverse objectives and criteria (Wiens et al., 2004). This renders it difficult to determine whether actions have or have not been successful at progressing a population or species toward a recovered state, and for managers to learn from these outcomes.

Despite recent scientific focus, stewardship, and legal efforts, both recovery and progress towards recovery are evident for very few species at risk (Boates and Fenton, 2011). Though the current paradigm in conservation biology is to avoid the extinction of species or populations, there is a need to shift from ad hoc prevention of population collapse towards facilitating recovery and fostering healthy and resilient ecosystems (Redford et al., 2011). Definitional problems of recovery present a significant challenge to this shift.

To overcome this problem, it is imperative to clarify what is meant by the terms 'recovery' and 'recovered', so as to permit the development of science-based targets (Jones and Schmitz, 2009). These terms should be enshrined in a legal mandate that is automatically triggered on reaching pre-defined indicator benchmarks (Wakeford et al., 2009). Policy decisions need to begin from a scientific understanding of recovery in order to ensure that recovery actions remain within the realm of scientific validity and effectiveness (Martín-López et al., 2009). It has been almost two decades since the first recommendations that federal and conservation agencies adopt formal criteria from which recovery goals could be measured to move towards separating biology and politics in the recovery process (Tear et al., 1995), yet no clear criteria to define recovery have been developed.

The problem of defining recovery is not a uniquely ecological issue; central to many medical sciences is the recovery of patients to pre-illness levels of functionality (Bellack, 2006). Though human individuals and ecological units differ, the status of both can be understood through an assessment of health. We believe much of what the medical sciences have learned can inform our understanding of recovery in ecological systems. The health of ecosystems, species, and populations is a well-developed concept within the field of conservation biology, allowing for transferable lessons from medicine.

Our objectives are to (1) review the current definitions of recovery in (1.1) academic literature, (1.2) legislation, (1.3) medical sciences; and (2) propose a process of recovery defined in five discrete stages, applying lessons learned from 1.1, 1.2, 1.3. Our framework aims to unify recovery definitions and strategies to help provide tools for overcoming the low success rates of effecting species recovery through existing legislation and ad hoc recovery plans.

1.1. Recovery in academic literature

In academic literature there is no single definition of 'recovery' (Lotze et al., 2011), nor what constitutes a 'recovered' state for a species. Recovery is considered 'an elusive concept' (Goble, 2009). Though much work has been done in the realm of research on the recovery of species at risk, many papers do not explicitly define their terminology (e.g. Lawler et al. 2002; Myers and Worm 2005; Poos et al. 2008). Definitions of the term 'recovery' vary in level of detail and complexity.

For example, Gårdmark et al. (2003) define recovery as '*the regrowth of a population after a crash to a size of one order of magnitude to the pre-decline population size*'; referring purely to population numbers. This definition uses the term 'recovery' to refer to a state, rather than a process, and it is defined according to relatively simple criteria. For Tear et al. (1995), recovery is the '*return of a wild population to a viable, self-sustaining level*'; hence recovery is referred to as both the process towards, and the end-state of, a recovered species. Hutchings et al. (2012) define recovery as a process, whereby it is *'a reversal of declines and achievement of predefined targets relating to metrics of persistence such as abundance or density, range distribution, and genetic/phenotypic variability'* (Hutchings et al. 2012). Though this latter definition correctly recognizes recovery as a process, its vagueness may be prohibitive for management action.

Recovery in biological conservation, or the process of moving towards a recovered state, can be described by conditions internal to the population (a population-based approach), e.g. changes in abundance with regard to a particular baseline (Lotze et al., 2011), by conditions external to the population, e.g. changes in a population's reliance on human intervention (Scott et al., 2005) or a mix of the two (Sanderson, 2006). Differences in level of detail and complexity are also apparent in definitions of what constitutes a recovered state. Schaffer and Stein (2000) formulated the 3-R framework of representation, resiliency, and redundancy, which are characteristics needed for a species to be considered recovered: a species should be present in many large populations arrayed across a range of ecological contexts (Schaffer and Stein, 2000). Redford et al. (2011) apply this 3-R framework, whereby a species is recovered or successfully conserved when it: (a) is self-sustaining demographically and ecologically, (b) is genetically robust, (c) has healthy populations, (d) has representative populations distributed across the historical range in ecologically representative settings, (e) has replicate populations within each ecological setting, and (f) is resilient across the range.

To delineate specific targets for a recovered state, it is necessary to establish a baseline population level. Baselines to delineate a recovered state (and measure recovery progress) vary from a historical, pre-disturbed state (Lotze et al., 2011) to a level of some theoretically hypothesized maximum potential, such as maximum sustainable yield (Schaefer, 1954). What baseline is chosen or what the targets of a population should be are subject to considerable debate (Sanderson, 2006). The issue is complicated further by shifting historical baselines–assessing recovery with reference to an uncertain and moving target (Pauly, 1995; Wiens et al., 2004) and problems associated with assuming a steady-state equilibrium (Jones and Schmitz, 2009).

Recovery has been defined by some authors as spanning a continuum of stages. For Redford et al. (2011), a species may pass through semi-stable states including '*captively managed*', '*intensively managed*', '*lightly managed*' and '*conservation dependent*' before reaching a fully recovered (self-sustaining) state. Though definitions vary widely between authors, a number of consistently important elements merge: differentiating the process of recovery from the state, establishing a baseline, and delineating stages are important and generalizable concepts to incorporate into a universal definition.

1.2. Recovery in legislation

We examined existing legal definitions of recovery used in the national species at risk legislation of the United States, the European Union, Australia, Bolivia and New Zealand to identify legal definitions of recovery and recovered status, as well as the recovered state aspired to in their legislation. In many cases, implicit definitions of recovery and recovered state had to be inferred due to a lack of explicit definitions. We selected these regions for investigation based on components used in the prioritization of conservation efforts (Reid, 1998): ranking high in threats (U.S. and E.U.), ranking high in species richness (Australia and Bolivia), and ranking high in endemism (New Zealand) (Kier et al., 2009; Secretariat of the Convention on Biological Diversity, 2001; Slingenberg et al., 2009).

In the U.S., the key piece of species at risk legislation is the *Endangered Species Act* (U.S.C., 1973). Legal protection under the *Endangered Species Act* is not extended to species that are de-listed, therefore, a species is recovered from a legal point of view when it can no longer be considered threatened ('*any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range*'), endangered or extinct. Though the U.S. Fish and Wildlife Service defines recovery as '*the process by which the decline of a threatened or endangered species is arrested or reversed, and threats to its survival are neutralized, so that its long-term survival in nature can be assured*' (U.S. Fish and Wildlife Service, 1992), such a definition is not carried forward into the text of the Act.

The E.U.'s *Bird Directive* (European Commission, 2009) and *Habitat Directive* (European Commission, 1992) provide legal protection for bird species and habitat. These pieces of legislation do not define recovery or recovered state, but the objective for species and their habitat is to achieve '*favourable status*'. To achieve this, a species currently classified as endangered, vulnerable, rare, or endemic, must have *'its natural range of habitat stable or increasing'; 'the specific structure and functions necessary for its long-term maintenance exist now and for the foreseeable future'*; or *'the conservation status of a typical species must be favourable'* (e.g. '*their population dynamics is associated with long-term viability'; 'natural range is not being reduced, nor in the foreseeable future'; 'there is sufficiently large habitat to maintain populations on a long-term bases*'). Recovery from a legal perspective, then, is the process of restoration of populations and their habitat to this favourable status, whereby recovered means that species and their habitat are at this favourable status.

In Australia, the *Environment Protection and Biodiversity Conservation Act* (Commonwealth of Australia, 1999) provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places, and prescribes requirements for recovery plans. This act does not specifically define recovery, or a recovered or healthy species. Legal protection is extended to species considered threatened, which is when it is at least considered 'vulnerable', defined as '*not critically endangered or endangered; and (b) it is facing a high risk of extinction in the wild in the medium-term future (...)*'. In the *Endangered Species Protection Act* (Commonwealth of Australia, 1992) a species is considered vulnerable *'at a particular time if, within the next 25 years, the species is likely to become endangered unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate'.*

In Bolivia, the Ley de Derechos de la Madre Tierra (Estado Plurinacional de Bolivia, 2010) gives Mother Earth and all components of nature the right: 'to life'; 'to diversity of life'; 'to continue vital cycles and processes free from human alteration'; 'to pure water'; 'to clean air'; 'to balance'; 'not to be polluted'. The State is responsible for the recovery and protection of Mother Earth and her components and must develop policies and actions of prevention, early warning, protection, precaution, to prevent human activities that lead to the extinction of populations, cycles and processes that are part of Mother Earth. The state must guarantee species' resilience to cope with stressors, without a significant change to structure and function (Estado Plurinacional de Bolivia, 2010). These rights and obligations could implicitly be included in the definition of a recovered status, however, criteria for when these rights and obligations have been met are not available. The law that governs protection of species and habitats and management of human activities impacting on species is the *Ley de Vida Silvestre, Parques Nacionales, Caza y Pesca* (Estado Plurinacional de Bolivia, 1975). This law prescribes that necessary measures must be taken to preserve or restore the habitat of wildlife -particularly for endangered species-requiring plans that enable recovery, restoration and preservation of species and habitats. The Ley de Medio Ambiente (Estado Plurinacional de Bolivia, 1992) states that State and Society shall ensure the protection, conservation and restoration of wildlife, both aquatic and terrestrial, particularly endemic species, restricted distribution, threatened, and endangered species. However, what constitutes recovery or recovered status is not defined in these laws, and no criteria for recovery of species at various levels of endangerment are specified.

According to the Department of Conservation (2013) New Zealand's species are protected through the *Marine Mammals Protection Act* (Government of New Zealand, 1978), the *Native Plants Protection Act* (Government of New Zealand, 1934), *Trade in Endangered Species Act* (Government of New Zealand, 1989) and the *Wildlife Act* (Government of New Zealand, 1953). None of these acts contain a definition of recovery or what constitutes a recovered or healthy species. The *Wildlife Act* declares all wildlife to be absolutely protected, except for wildlife listed in Schedules 1 to 5, which includes species that are not protected, partially protected or that may be hunted or killed. The designation of threatened or non-threatened is given according to a threat classification system (Townsend et al., 2008). This system classifies species as extinct, threatened (subdivisions critical, endangered, vulnerable), at risk (subdivisions declining, recovering, relic, naturally uncommon) or not threatened. A species will be listed as not threatened and will consequently not enjoy legal protection unless it falls under the extinct, threatened or at risk category. Not-threatened listing (an implicit recovered state) will occur when the number of mature individuals is higher than 100,000 or if the total predicted and ongoing population trend due to existing threats is stable or increasing by more than 10% (and other, secondary criteria are available).

Interestingly, legal recovery has been defined on a more quantitative and somewhat more consistent basis for marine ecosystems. The U.S., E.U., Australia, and New Zealand use the idea of a reference points relative to an expected maximum sustainable yield of the fish stock to determine when population abundances have recovered or have declined below recommended levels, and harvest quotas are altered depending on these levels (Australian Government, 2007; European Commission, 2002; Government of New Zealand, 1996; U.S. Department of Commerce, 1998). The aim of both the Australian and U.S. Government is to not let populations drop below a limit reference point of abundance of approximately 50% of the expected maximum sustainable yield (Hilborn and Stokes, 2010; Hutchings et al., 2010). The U.S. aims to recover fish stocks to a target reference point of biomass levels capable of producing maximum sustainable yield on a continuing basis (U.S. Department of Commerce, 1998), whereas Australia aims for recovery higher than maximum sustainable yield (Grafton et al., 2007), i.e. higher at an average of or higher than the Maximum Economic Yield; the level of biomass that creates the largest positive difference between total revenues and costs of fishing (OECD, 2012).

Of the five jurisdictions examined, no legislation regarding species and ecosystem conservation explicitly defines recovery or what constitutes a recovered or healthy status. We can infer the meaning of recovered status from a legal point of view as implied the state under which a species or ecosystem no longer receives legal protection from this legislation. This is often the case when species are reassessed into a lower threat category such as 'vulnerable' or 'not threatened', leaving them effectively recovered according to law. However, lower listing may not mean that decline has stopped or a population has recovered in a biological or ecological sense. The population may have stabilized, or decline may have merely slowed or become more difficult to detect. This can lead to a downward shifting baseline for population levels and/or range of a species. This could result in situations where species have lost the majority of their population, but declines have slowed, still resulting in a label of 'recovered' when no recovery has in fact occurred.

Just as the scientific literature does not apply one single definition of recovery, nor of recovered status, neither does the legislation of various countries. We found divergence in the implicit definitions of recovery and recovered status or healthy ecosystem, ranging from 'no longer threatened' to 'favourable status' (Table 1). We also found divergence in the species protection legislation criteria set to define legal recovery, ranging from qualitative to quantitative criteria.

1.3. Recovery in medicine

In light of competing and incongruous definitions of species recovery and recovered state in academic literature and legislation, it is useful to consider definitions from more clearly-defined fields. In the medical sciences the idea of stages of recovery dates back to at least 1946 (Russell and Nathan, 1946) and has been used in many medical disciplines including mental health, neurology (especially stroke and head trauma), addiction treatment, rehabilitation, surgery, and cardiology (De Leon, 1996; Liberman et al., 2002; Steward, 1975). Though specific definitions of the stages of recovery vary across fields, they feature common themes that can help guide our view of recovery in conservation biology (for example, Bottrill et al. (2009) used the medical concept of triage to suggest an approach for species conservation given limited available funds).

Medically, recovery is considered the process of moving patients from a state of impaired or declining functionality and rehabilitating them to a state of pre-disease functionality (or as close as possible) (Andresen et al., 2006; De Leon, 1996). In each of the above medical fields this framework has been suggested as a template for defining the recovery process, although the first two stages may be implicit or not considered part of the medical recovery process per se but more so thought of as part of a disease-treatment-recovery continuum.

The first stage in any medically-assisted recovery process is the diagnosis stage, in which a patient presents with symptoms of illness or receives a medical check-up. A diagnosis is made of the cause of symptoms to the best of the practitioner's ability, the severity of the risk to the patient's health is assessed, and an appropriate treatment strategy is determined (De Leon, 1996).

The second stage is the initiation of the treatment process, with the aim to stop or reverse declining health by eliminating or minimizing the threat(s) to the patients' health. If the patients' health continues to deteriorate (there is no evidence of stabilization or 'recovery'), alternative treatment procedures will be implemented. Patient monitoring is at a maximum to ensure that the treatment is working as expected (Steward, 1975). These first two stages can occur very rapidly (e.g. resetting a broken limb), or can take a great deal of time (e.g. diagnosis and treatment of mental illness).

The third stage is stabilization of the patient, when decline in health has ceased. Though functionality is still impaired, deterioration is not expected and monitoring continues (Steward 1975). In some situations, stabilization of the patient is the end goal of treatment and no further recovery to pre-disease or trauma functionality is likely or possible (Bond, 1979).

The fourth stage is rehabilitation of the patient's functionality (Andresen et al., 2006; Steward, 1975). In this stage current patient health is generally comparable to pre-disease health, but full function has not been regained. Some metric of individual functionality is used to assess the success of the rehabilitation process. During this potentially prolonged period the patient is regularly monitored (though less so than in stages 2 or 3) to ensure they are returning towards pre-disease health (or the nearest equivalent) and do not suffer a relapse.

The fifth and final stage is the recovered stage, which encompasses a return to pre-illness functionality and a lack of symptoms over a relatively long period of time (1–5 years) (Bellack, 2006; Harrow et al., 2005; Liberman et al., 2002; Torgalsbøen, 2006).

These medically defined stages highlight the need for evaluation and monitoring throughout the recovery process, and accommodate the fact that not all patients will experience the same linear forward progression through each stage. These considerations apply directly to the case of populations, species, or ecological systems, which can be considered the patient for our purposes.

2. The process of population recovery

Building on these general medical definitions and stages of recovery, as well as previous work within the field of conservation biology, we delineate the recovery process in five stages as below. The term 'population' will be used, though it could be replaced with species, ecological system, or other unit of consideration.

2.1. Stage 1: Diagnosis

The recovery process is initiated by a review performed by scientists and experts, who will then pass over the information to policy-makers (such as government and/or NGO), whereby a population has been determined to be 'at risk'. At this time, the 'at risk' status may also be legally enshrined by the jurisdiction in question. To begin efforts towards the recovery process, threats to the population are determined and a monitoring protocol (if not already in place) is implemented. An estimate of the pre-decline health of the population should be determined, if possible, as a reference point and used as a potential target for a recovered state. A recovery plan for treatment that clearly defines targets for a recovered state and actions required for a population to achieve that state (or as close as possible) should be implemented.

Table 1
Implicit legal definitions of a recovered state in national/governing body legislation for Australia, Bolivia, the European Union, New Zealand, the United States of America.

Jurisdiction	Implicit legal definitions of recovered state in legislation	Criteria to define recovered status
Australia	Species is no longer listed as vulnerable (Commonwealth of Australia 1992, 1999)	Quantitative
Bolivia	Species have the right to life, to diversity of life, to continue vital cycles and processes free from human alteration, to pure water and clean air; to balance, and to not be polluted (Estado Plurinacional de Bolivia 2010). Species is no longer of restricted distribution, endemic, threatened or endangered (Estado Plurinacional de Bolivia 1992); Species and habitat have been recovered, restored and preserved (Estado Plurinacional de Bolivia 1975)	Qualitative
E.U.	Endangered, vulnerable, rare or endemic species have achieved '*favourable status*' (European Commission 1992, 2009)	Qualitative
New Zealand	Species is no longer listed as threatened or at risk (Government of New Zealand 1953; Townsend et al., 2008)	Quantitative
U.S.	Species is no longer listed as threatened or endangered	Qualitative

Just as with medical sciences, early intervention is critical; the longer it takes to diagnose a population the more difficult it will be to restore the populations' health to pre-decline levels (Neubauer et al., 2013). It is expected that developing accurate assessments and predictions of decline, and implementing mitigation strategies before populations suffer irreversible harm, will improve chances of recovery (Hutchings et al., 2012; Hutchings, 2000; Neubauer et al., 2013).

During diagnosis, it is crucial to determine the correct population health metrics (PHMs) to measure. PHMs are indices that allow for quantification of recovery, and can be used to set targets for the 'recovered state' designated in the recovery plan. PHMs may include quantified measures of abundance, genetic diversity, age diversity, size diversity, number of metapopulations, spatial extent, habitat connectivity, or many other variables depending on the availability of information and the nature of the population in question. Each population will be associated with its own complex of key indicators, depending on its life history characteristics, and PHMs should be selected based on available information and the best current science for that population.

A simple and potentially useful analogy to medical practice may be a first step emergency assessment of 'ABCs' Airway, Breathing, and Circulation). This would include some numerical measure of these variable groups (Fig. 1). This may be a useful organizational tool for managers, though a more comprehensive evaluation of relevant PHMs and their interactions should still be undertaken (see Fig. 2).

We recognize that in many situations some or all of this information will not be readily available, but it is crucial to use some measure of PHMs to quantify population health and evaluate outcomes. In addition, the recovery plan should outline what level of each individual PHM would constitute a fully recovered state and the likelihood of it being reached (stage 5, which may not be realistic for all populations due to irreversible habitat loss). Furthermore, our framework does not explicitly include methodology for determining potential targets for recovered states, or specific methods for assessing PHMs, as these may vary greatly depending on the life history of the population under consideration. However, we stress that target reference points should be set using the best available science. We acknowledge that there are significant problems in determining the appropriate methods for selecting a baseline and assuming a steady-state equilibrium (see Lotze et al. (2011)) for a summary in marine ecosystems, Scott et al. (2005) for a discussion of these issues in a terrestrial context, and Tear et al. (2005) for a discussion of shifting baselines). Though it is beyond the scope of this paper, considerable work needs to be done to tackle these challenges. As a basic starting point for setting targets, we refer to the recommendation of Lotze et al. (2011): "To place recovery into context, it can be useful to relate these measures to the magnitude, rate and time span of former depletion or degradation, or to scale them to an expected rate of response, such as population growth rate, generation time or succession rate."

2.2. Stage 2: Treatment

The second stage involves the implementation of conservation action(s) outlined in the recovery plan. Efforts are made to remove or reduce threats to the population (e.g. minimizing habitat loss, reducing or ceasing harvesting, removing an invasive species, etc.) and decline has slowed over the past 10 years or 3 generations, whichever is longer[1]. From this stage forward, it is of paramount importance that the population is closely monitored for evidence of further deterioration of health (a decline in any of the PHMs, which could be expressed through habitat loss or degradation, abundance decline, genetic homogenization, etc.). Intensive monitoring of the population's health will begin, to ensure that treatment begins to work after implementation (stage 3). Managers should also be prepared for implementation of alternative treatment strategies if health continues to deteriorate.

2.3. Stage 3: Stabilization

This third stage occurs when the PHMs have stabilized (e.g. population abundance has stopped declining for a prolonged period, 10 years or 3 generations, or habitat loss has ceased, etc.), and primary threats have been minimized or removed. PHMs remain at significantly lower levels than in the pre-decline period, and/or they may show weak evidence of increase. For some populations no recovery to previous pre-decline health is possible due to permanent environmental, ecosystem, or life history changes, in which case, this stage of recovery may be the highest possible that can be achieved.

2.4. Stage 4: Rehabilitation

This stage is marked by a prolonged increase in PHMss (e.g. at least 10 years or 3 generations). Primary threats have been eliminated and the population has been recorded, by the best available measures, to be progressing towards the targets developed in the recovery plan.

[1] For several of the stages, we have provided stage durations based on length of time in years and/or generation length based in accordance with existing considerations in IUCN guidelines. These time frames are an attempt to balance the needs of making a timely assessment of conservation success with ensuring the population trajectories are not merely the result of environmental stochasticity. For strongly cyclical populations with long periodicity between cycles, the durations we have specified are likely inadequate. For long-lived species for which two generations would exceed reasonable time frames for management, a shorter duration may be necessary.

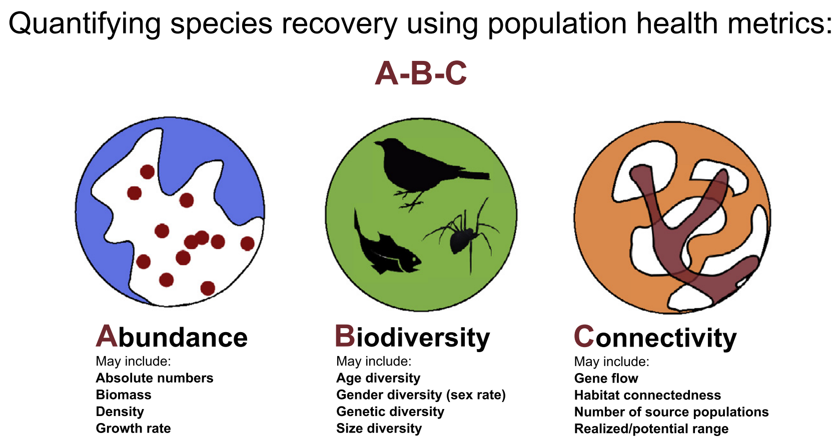

Fig. 1. Examples of population health metrics used when to quantify ABC (abundance, biodiversity, and connectivity) indicators when during assessment of the recovery process and recovered states.

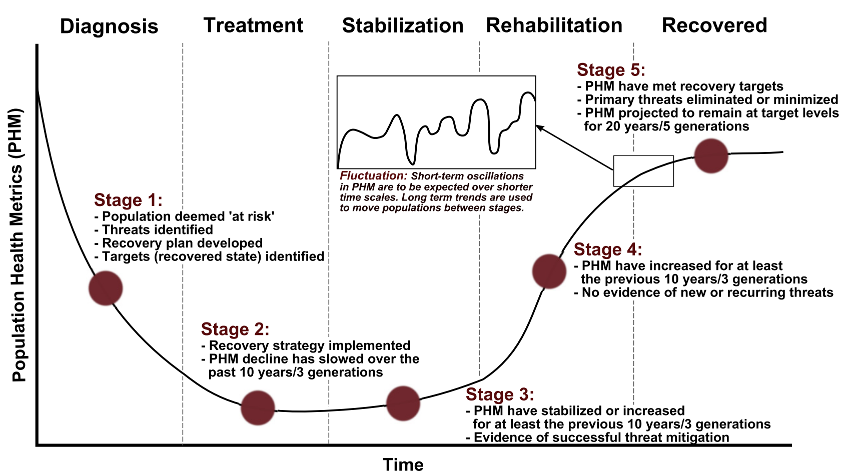

Fig. 2. An example of a population trajectory through the five stages of recovery (diagnosis, treatment, stabilization, rehabilitation, recovered status).

2.5. Stage 5: Recovered

A population reaches the final or recovered stage when marked by a stabilization of s at or above the recovered state quantified in stage 1. PHMs must remain stable at or above this level for a prolonged period (10 years or 3 generations), after the requirements for stage 4 have been met. Based on knowledge of current and potential future threats, population PHMs would be projected to remain at these levels for the foreseeable future (i.e. 20 years or 5 generations). Populations unable to return to pre-decline levels without ongoing management actions, or whose recovery was perpetually limited by permanent habitat loss or other factors, would not be able to achieve this stage of recovery.

2.6. Comparison to existing frameworks

To include a measure of time, as a starting point in the discussion, we have suggested the use of 10 years and 3 generations (whichever is longer) in accordance with IUCN guidelines for assessing the status of species at risk (IUCN Species Survival Commission, 2000). This is in an effort to balance the needs of the recovery work occurring in the field (in which feedback on the effectiveness of conservation action is vital) with the biological and ecological realities that suggests that a lengthy period of time is needed to assess population trends. Our aim in using IUCN guidelines is to facilitate integration of a measured recovery process into existing policy frameworks and legislation. It is likely the correct time frame can only be determined on a per species/population/ecological unit basis through detailed field studies. However, without following a consistent recovery procedure, such as the one we have outlined, the necessary data may never be available.

Though many authors have suggested scientific components that should be included during the recovery planning process (e.g. Carroll et al. 1996; Foin et al. 1998; Sanderson 2006) or discussed the need for recovery planning within a larger strategic framework (e.g. Lundquist et al. 2002; Farrier et al. 2007; Mooers et al. 2010), the process of recovery has not be specifically delineated. To our knowledge, Redford et al's. (2011) taxonomy of recovery for vertebrates is the closest approximation of such a guide, whereby species are assigned to one of four states: captively managed, intensively managed, lightly managed, and self-sustaining. Though these states highlight the importance of management action, it lacks timelines, quantitative targets, and provisions for monitoring. Additionally, the target recovered state, 'self-sustaining', is understood in terms of lack of human interference, whereas our process is understood in terms of the population dynamics of the species or ecological unit under consideration. Our present guide builds on the work of Redford et al. (2011) by explicitly delineating quantitative recommendations and targets for each of the stages of recovery, and including essential provisions for diagnosis and monitoring.

Whereas other legislative or academic frameworks have included some aspects of generalizability across most situations, a quantification of recovery stages, and a systematic approach, -to our knowledge- no prior suggestions have included all three of these crucial aspects within a single framework, as in the case of the 5-stage classification presented here.

3. Conclusion

In medicine, a patient is identified to be at risk, and then treated with the intent of returning them to health-not merely ensuring they do not perish. Similarly, we believe the aim of conservation biology should not be to keep populations on life support, but to maintain healthy populations. To accomplish this, we must distinguish between the process of recovery and the end-state of recovered, and implement quantifiable, generalizable guidelines that ensure optimal outcomes. We propose five stages for the recovery process that should be implemented as soon as possible after populations are diagnosed as being at risk. We propose using population health metrics (PHMs) based on measures already developed by many agencies, such as the IUCN (such as habitat extent, threat, and/or population size). These indicators should be quantified to set targets for a recovered state, and monitor population health. We have delineated of the process of recovery into five stages (Diagnosis, Treatment, Stabilization, Rehabilitation, and Recovered), which could be used in international, national, and institutional frameworks to overcome existing significant problems. These problems, as identified within the academic literature and current legislation, include: unpredictable decision making, divergence and inconsistencies in recovery and recovered status definitions, criteria, objectives and plans, an inability to measure actual recovery, and an inability to learn from failure and success. The framework that we have proposed would allow for a quantified, generalizable, systematic and accountable method that could be used for different species and ecological units at different jurisdictional levels. This consistency and measured approach could be substantially useful for improving the likelihood of populations successfully reaching recovered status.

Acknowledgements

The authors would like to thank Dr. Jeff Hutchings, Dr. H. Resit Akcakaya, Dr. Robin Waples, and other member of the NCEAS ‘‘Red Flags and Species Endangerment’’ workgroup for helpful comments on ideas about recovery. Dr. Marty Leonard, in particular, contributed helpful and detailed commentary on an early version of this work, as well as our two anonymous referees for their valuable perspectives. We would also like to thank Veronik Campbell, Anna Magera, Lauren Burke, and Sarah Gutowksy for engaging conversations on this topic. Finally, we would like to thank Dalhousie University Biology Department, the Prins Bernhard Cultuur Fonds, and NSERC for the funding that allowed for our cooperation.

References

Andresen, R., Caputi, P., Oades, L., 2006. Stages of recovery instrument: development of a measure of recovery from serious mental illness. Aust. N. Z. J. Psychiatry 40, 972–980.
Australian Government, 2007. Commonwealth Fisheries Harvest Strategy Policy Guidelines.
Bellack, A.S., 2006. Scientific and consumer models of recovery in schizophrenia: concordance, contrasts, and implications. Schizophr. Bull. 32, 432–442.
Boates, J.S., Fenton, M.B., 2011. Flagship Species – Flagship Problems: recovery of species at risk and the conservation of biodiversity. Can. J. Zool. 89, 369–370.
Bond, M.R., 1979. The stages of recovery from severe head injury with special reference to late outcome. Int. Rehabil. Med. 1, 155–159.
Bottrill, M.C., Joseph, L.N., Carwardine, J., Bode, M., Cook, C., Game, E.T., Grantham, H., Kark, S., Linke, S., McDonald-Madden, E., Pressey, R.L., Walker, S., Wilson, K.A., Possingham, H.P., . Finite conservation funds mean triage is unavoidable. Trends Ecol. Evol. 24, 183–184.
Carroll, R., Augspurger, C., Dobson, A., Franklin, J., Orians, G., Reid, W., Tracy, R., Wilcove, D., Wilson, J., 1996. Strengthening the use of science in achieving the goals of the Endangered Species Act: an assessment by the Ecological Society of America. Ecol. Appl. 6, 1–11.
Commonwealth of Australia, 1992. Endangered Species Protection Act.
Commonwealth of Australia, 1999. Environment Protection and Biodiversity Conservation Act – C2005C00338.
Coristine, L.E., Kerr, J.T., 2011. Habitat loss, climate change, and emerging conservation challenges in Canada. Can. J. Zool. 89, 435–451.
COSEWIC, 2011. COSEWIC's Assessment Process and Criteria.
D'Elia, J., McCarthy, S., 2010. Time horizons and extinction risk in endangered species categorization systems. Bioscience 60, 751–758.
De Leon, G., 1996. Integrative recovery: a stage paradigm. Subst. Abus. 17, 51–63.
Department of Conservation New Zealand, 2013. Key New Zealand Laws and Regulations [WWW Document].
Elphick, C.S., Reed, J.M., Bonta, J.M., 2001. Correlates of population recovery goals in endangered cirds. Conserv. Biol. 15, 1285–1291.
Estado Plurinacional de Bolivia, 1975. Ley de Vida Silvestre, Parques Nacionales, Caza y Pesca. Decreto Ley 12301, publicado en Gaceta Oficial del Estado Pluronacional de Bolivia Edición, 771.
Estado Plurinacional de Bolivia, 1992. Ley de Medio Ambiente.
Estado Plurinacional de Bolivia, 2010. Ley de Derechos de la Madre Tierra. Ley 71, Publicado en Gaceta Oficial del Estado Pluronacional de Bolivia Edición 205NEC. LA ASAMBLEA LEGISLATIVA PLURINACIONAL.
European Commission, 1992. Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora.
European Commission, 2002. Council Regulation (EC) No. 2371/2002 of 20 December 2002 On the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Off. J. Eur. Communities L, 98.
European Commission, 2009. Council Directive 2009/147/EC on the Conservation of Wild Birds (codified version of Directive 79/409/EEC).
Farrier, D., Whelan, R., Mooney, C., 2007. Threatened species listing as a trigger for conservation action. Environ. Sci. Policy 10, 219–229.
Foin, T.C., Riley, S.P.D., Pawley, A.L., Ayres, D.R., Carlsen, T.M., Hodum, P.J., Switzer, P.V., 1998. Improving recovery planning for threatened and endangered species. Bioscience 48, 177–184.
Gårdmark, A., Enberg, K., Ripa, J., Laakso, J., Kaitala, V., 2003. The ecology of recovery. Ann. Zool. Fenn. 40, 131–144.
Goble, D.D., 2009. The Endangered Species Act: What we talk about when we talk about recovery. Nat. Resour. J. 49, 1–44.
Government of New Zealand, 1934. Native Plants Protection Act.
Government of New Zealand, 1953. Wildlife Act.
Government of New Zealand, 1978. Marine Mammals Protection Act.
Government of New Zealand, 1989. Trade in Endangered Species Act.
Government of New Zealand, 1996. Fisheries Act.
Grafton, R.Q., Kompas, T., Hilborn, R.W., 2007. Economics of overexploitation revisited. Science 318 (80), 1601.
Harrow, M., Grossman, L.S., Jobe, T.H., Herbener, E.S., 2005. Do patients with schizophrenia ever show periods of recovery? A 15-year multi-follow-up study. Schizophr. Bull. 31, 723–734.
Hilborn, R., Stokes, K., 2010. Defining overfished stocks: have we lost the plot? Fisheries 35, 113.
Hutchings, J.A., Butchart, S.H.M., Collen, B., Schwartz, M.K., Waples, R.S., 2012. Red flags: correlates of impaired species recovery. Trends Ecol. Evol. 27, 542–546.
Hutchings, J.A., 2000. Collapse and recovery of marine fishes. Nature 406, 882–885.
Hutchings, J.A., Minto, C., Ricard, D., Baum, J.K., Jensen, O.P., 2010. Trends in the abundance of marine fishes. Can. J. Fish. Aquat. Sci. 67, 1205–1210.
IUCN Species Survival Commission, 2000. IUCN Red List Categories and Criteria Version 3.1, second ed.
Jones, H.P., Schmitz, O.J., 2009. Rapid recovery of damaged ecosystems. PLoS One 4, e5653.
Kier, G., Kreft, H., Lee, T.M., Jetz, W., Ibisch, P.L., Nowicki, C., Mutke, J., Barthlott, W., 2009. A global assessment of endemism and species richness across island and mainland regions. Proc. Natl. Acad. Sci. USA 106, 9322–9327.
Lawler, J.J., Campbell, S.P., Guerry, A.D., Kolozsvary, M.B., O'Connor, R.J., Seward, L.C.N., 2002. The scope and treatment of threats in endangered species recovery plans. Ecol. Appl. 12, 663–667.
Liberman, R.P., Kopelowicz, A., Ventura, J., Gutkind, D., 2002. Operational criteria and factors related to recovery from schizophrenia. Int. Rev. Psychiatry 14, 256–272.
Lotze, H.K., Coll, M., Magera, A.M., Ward-Paige, C., Airoldi, L., 2011. Recovery of marine animal populations and ecosystems. Trends Ecol. Evol. 26, 595–605.
Lundquist, C.J., Diehl, J.M., Harvey, E., Botsford, L.W., 2002. Factors affecting implementation of recovery plans. Ecol. Appl. 12, 713–718.
Martín-López, B., Montes, C., Ramírez, L., Benayas, J., 2009. What drives policy decision-making related to species conservation? Biol. Conserv. 142, 1370–1380.
Mooers, A.O., Doak, D.F., Scott Findlay, C., Green, D.M., Grouios, C., Manne, L.L., Rashvand, A., Rudd, M., Whitton, J.A., 2010. Science, policy, and species at risk in Canada. Bioscience 60, 843–849.
Myers, R.A., Worm, B., 2005. Extinction, survival or recovery of large predatory fishes. Biol. Sci. 360, 13–20.
Neubauer, P., Jensen, O.P., Hutchings, J.A., Baum, J.K., 2013. Resilience and recovery of overexploited marine populations. Science 340 (80), 347–349.

OECD, 2012. Inventory of National and Regional Approaches to Fisheries Rebuilding Programmes: Australia. In: Rebuilding Fisheries: The Way Forward, pp. 1–14.
Pauly, D., 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends Ecol. Evol. 10, 430.
Poos, M.S., Mandrak, N.E., McLaughlin, R.L., 2008. A practical framework for selecting among single-species, community-, and ecosystem-based recovery plans. Can. J. Fish. Aquat. Sci. 65, 2656–2666.
Redford, K.H., Amato, G., Baillie, J., Beldomenico, P., Bennett, E.L., Clum, N., Cook, R., Fonseca, G., Hedges, S., Launay, F., Lieberman, S., Mace, G.M., Murayama, A., Putnam, A., Robinson, J.G., Rosenbaum, H., Sanderson, E.W., Stuart, S.N., Thomas, P., Thorbjarnarson, J., 2011. What does it mean to successfully conserve a (vertebrate) species? Bioscience 61, 39–48.
Reid, W.V., 1998. Biodiversity hotspots. Trends Ecol. Evol. 13, 275–280.
Russell, W.R., Nathan, P.W., 1946. Traumatic amnesia. Brain 69, 280–300.
Sanderson, E.W., 2006. How many animals do we want to save? The many ways of setting population target levels for conservation. Bioscience 56, 911–922.
Schaefer, M.B., 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bul. Int. -Amer. Trop. Tuna Com. 1, 247–285.
Schaffer, M.L., Stein, B.A., 2000. Safeguarding our precious heritage. In: Stein, B.A., Kutner, L.S., Adams, J.S. (Eds.), Precious Hertiage: The Status of Biodiversity in the United States. Oxford University Press, Oxford, New York, pp. 301–321.
Scott, J.M., Goble, D.D., Wiens, J.A., Wilcove, D.S., Bean, M., Male, T., 2005. Recovery of imperiled species under the Endangered Species Act: the need for a new approach. Front. Ecol. Environ. 3, 383–389.
Secretariat of the Convention on Biological Diversity, 2001. Global Outlook I. Montreal, Canada.
Slingenberg, A., Braat, L., Windt, H. van der., Rademaekers, K., Eichler, L., Turne, K., 2009. Study on Understanding the Causes of Biodiversity Loss and the Policy Assessment Framework (No. DG.ENV.G.1/FRA/2006/0073). Rotterdam, Netherlands.
Steward, D.J., 1975. A simplified scoring system for the post-operative recovery room. Can. Anaesth. Soc. J. 22, 111–113.
Tear, T.H., Kareiva, P., Angermeier, P.L., Comer, P., Czech, B., Kautz, R., Landon, L., Mehlman, D., Murphy, K., Ruckelshaus, M., Scott, J.M., Wilhere, G., 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. Bioscience 55, 835.
Tear, T.H., Scott, J.M., Hayward, P.H., Griffith, B., 1995. Recovery plans and the Endangered Species Act: are criticisms supported by data? Wildl. Res. 9, 182–195.
Torgalsbøen, A., 2006. What is recovery in scizophrenia? In: Davidson, L., Harding, C., Spaniol, L. (Eds.), Recovery From Severe Mental Illnesses: Research Evidence and Implications for Practice. Boston University Center for Psychiatric Rehabilitation, Boston.
Townsend, A.J., Lange, P.J. De, Duffy, C.A.J., Miskelly, C.M., Molloy, J., Norton, D.A., 2008. New Zealand Threat Classification System Manual. Wellington, New Zealand.
U.S. Department of Commerce, 1998. Magnuson-Stevens Fishery Conservation and Management Act; as Amended Through January 12, 2007.
U.S. Fish and Wildlife Service, 1992. Report to Congress. Washington, DC
U.S.C., 1973. Endangered Species Act, as Amended through the108th Congress, Inst. Environ. Sci., 940 E. NORTHWEST HWY, MT.
Wakeford, R.C., Agnew, D.J., Mees, C.C., 2009. Review of institutional arrangements and evaluation of factors associated with successful stock recovery plans. Rev. Fish. Sci. 17, 190–222.
Wiens, J.A., Day, R.H., Murphy, S.M., Parker, K.R., 2004. Changing habitat and habitat use by birds after the Exxon Valdez oil spill, 1989–2001. Ecol. Appl. 14, 1806–1825.