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Bending the curve: Operationalizing national Red Lists to customize conservation actions to reduce extinction risk

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ABSTRACT

Human activity is accelerating biodiversity loss despite international commitments to prevent extinction and habitat degradation. To bend the curve, international goals must be translated into national targets and actions. Tools to do this are highly needed, but scarce. We present a first attempt to operationalize national Red Lists by using the quantitative criteria of risk assessment as quantifiable objectives in a Red to Green framework. The framework allows for a systematic setting of conservation goals, with quantifiable conservation objectives, and identifying conservation actions to achieve these objectives. We developed an index of conservation outcome, modified from the Red List Index, to quantify the potential conservation outcomes of implementing suggested conservation actions. We tested the framework and index on 123 Red Listed species and habitats prioritized for conservation by the Norwegian government. The policy-defined goal was to downlist them by one Red List category by 2035. We identified land use change as the greatest threat. For 70% of species and 20% of habitats, knowledge was insufficient to recommend conservation actions. Further, due to unmanageable threats, alternative, lower-ambitioned goals were suggested for 30% of the species. Our case show that reaching national goals is difficult, but possible if main constraints are resolved. Through a systematic assessment of knowledge and conservation actions, the framework forms a solid foundation for developing national action plans for biodiversity conservation, allowing for prioritization and implementation of conservation actions and reporting on progress. This is an important first step to reach national targets defined from international goals.

1. Introduction

Biodiversity is undergoing rapid declines because of human activity (IPBES, 2019), with negative consequences for populations, species, communities, and ecosystems (Hughes et al., 2008; Ceballos et al., 2015), and for humanity (Cardinale et al., 2012; IPBES, 2019). Around one million species are threatened with extinction globally (IPBES, 2019), despite international ambitions to halt biodiversity loss. Through the Aichi Biodiversity Targets, in the 2011–2020 Strategic Plan for Biodiversity of the Convention on Biological Diversity (CBD), signatory countries have committed to work to prevent the extinction and improve the conservation status of threatened species. Despite these ambitions, the recent IPBES (2019) and CBD reports (Secretariat of the CBD, 2020a) show that globally, poor progress has been made towards fulfilling the Aichi Targets and that overall, the state of nature continues to decline, especially in the case of rare and endemic species, and species with particular adaptations and requirements (IPBES, 2019).

These policy targets are agreed at the international level; however, implementation is carried out at the national level. Therefore, to succeed in halting biodiversity loss, international policy must be translated into national actions. A roadmap for "bending the curve" that could be used to guide national actions has been suggested (Mace et al., 2018). The roadmap consists of three steps: 1) set a goal, 2) develop a set of measurable indicators/targets, and 3) identify a suite of actions to

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achieve the goal. It is critical to turn this roadmap into practical tools that conservation managers can use to deliver national commitments.

The IUCN Red List is a widely used approach that identifies species at risk of extinction (Mace et al., 2008) and ecosystems at risk of collapse (Keith et al., 2013). Many threatened species and ecosystems are “conservation reliant” (cf. Scott et al., 2010); i.e. they depend on continued management interventions or active conservation actions to persist. Consequently, Red Lists are important to inform and catalyse conservation actions (Akçakaya et al., 2018) and are often the first step to prioritizing the implementation of conservation actions (Miller et al., 2006; Fitzpatrick et al., 2007; IUCN, 2019). However, Red Lists do not prioritize conservation at regional or national scales as they do not identify specific actions, nor evaluate the feasibility or cost of improving the conservation status of species or ecosystems (Possingham et al., 2002; Mace et al., 2008; Collen et al., 2016). Nevertheless, Red Lists affect conservation practice through increasing scientific knowledge, providing an understanding of risk of extinction and collapse, and through access to funding and conservation activity (Betts et al., 2020). Also, regular updating of Red Lists allows for the calculation of the Red List Index (Butchart et al., 2007), a powerful tool to evaluate trends in biodiversity (e.g. Zamin et al., 2010; Henriques et al., 2020; Renjifo et al., 2020; Pacoureau et al., 2021). Further, by providing quantitative criteria for risk evaluation, Red Lists can be important for formulating quantitative conservation goals.

Conservation funds are limited, and several approaches for systematically prioritizing conservation actions, species, spatial units or threats, exist (e.g. Margules and Pressey, 2000; Joseph et al., 2009; Brazill-Boast et al., 2018; Carwardine et al., 2019). At the base of cost-effective prioritization lies an assessment of conservation benefit (the reduced extinction risk following implementation of actions), likelihood of success (feasibility of actions, anticipated effects) and costs (Joseph et al., 2009; Brazill-Boast et al., 2018). Previous studies of cost-effective prioritizations have, however, used subjective methods to quantify conservation benefit, such as expert assessment of change in conservation status due to management (e.g. Briggs, 2009; Brazill-Boast et al., 2018). Moreover, existing approaches do not necessarily provide mechanisms for translating international targets into national goals and actions. Here, we propose a novel approach to operationalizing national Red Lists, as a first step towards systematically planning conservation actions. We advance on previous work (Mace et al., 2008; Joseph et al., 2009; Keith et al., 2013; Brazill-Boast et al., 2018) by using the quantitative criteria of risk assessment (extinction risk for species, risk of ecosystem collapse for habitats) in a “Red to Green” framework. Our framework applies the Red List criteria to set measurable objectives and targets for a set of species and habitats, which is followed by the identification of conservation actions (which, where, and to what extent) needed to reach goals, and cost assessments of these actions. A further advance is that the framework allows for a systematic compilation of constraints, such as lack of knowledge and uncertainty of conservation action impact, which is essential for establishing budgeted work programmes to address national objectives and targets. In addition, we develop an index of conservation outcome as a measure of the potential impact of implementing conservation actions and the potential progress towards defined goals for conservation.

We test the framework on 123 Red Listed species and habitats in Norway, that the Norwegian Government prioritized for conservation in the Norwegian National Biodiversity Strategy and Action Plan (NBSAP; Norwegian Ministry of Climate and Environment, 2015). We use the index of conservation outcome to quantify how potential barriers, such as knowledge gaps or unmanageable threats, may constrain conservation outcomes, thus informing conservation managers of constraints to reaching national goals. We demonstrate the potential of the framework for improving the overall effectiveness of prioritizing and implementing conservation actions nationally or regionally to improve the status of Red Listed species and habitats, and to evaluate national progress towards biodiversity goals.

2. Methods

2.1. The Red to Green framework

An overview of the Red to Green framework is presented in Box 1 and Fig. 1. The Red to Green framework can be applied to any national or regional Red List. It consists of three stages (Box 1), each comprising several steps; collecting data (point 1), setting goals (point 2), and identifying conservation actions (point 3). A methods manual and a template for conducting an assessment of a Red Listed species or habitat (hereafter called Red List Object (RLO)) were developed (see Appendix A).

2.1.1. Collect data

Data are collected systematically following a standard protocol (Tables A1 and A2, Appendix A) and the knowledge status of each data topic (Box 1, point 1a) is then evaluated using the following five categories: Unknown (information unavailable); Outdated (old, not verified information); Poor (not sufficient to recommend actions); Good (knowledge gaps, but sufficient to suggest and describe actions); Very good (no knowledge gaps). By applying these categories, the framework identifies critical knowledge gaps that need to be bridged to be able to suggest or implement conservation actions. However, not all knowledge categories require a good knowledge status for describing actions. Data collection also includes the current Red List status (Box 1, point 1b) and threats to the RLO (Box 1, point 1c), as described in the national Red List, including the timing, scope, and severity of the threats. If no national Red List is available, the IUCN threat scheme could be applied (Salafsky et al., 2008, see also https://www.iucnredlist.org/resources/threat-classification-scheme). All threats are identified, including threat name, a short description, and assessments of timing, scope and severity (for details see Table A3).

2.1.2. Set goals

A conservation goal for each RLO, often set by government agencies based on international commitments, is specified (Box 1, point 2a). The goal should improve conservation status, e.g. observed as a downlisting in the Red List within a given time frame (a target year), and ideally the RLO should obtain a status of Least Concern (LC) within a given time frame. The goal should apply to the geographical scale assessed in the relevant national or regional Red List.

The conservation goal is supported by several specific and quantifiable objectives (Box 1, point 2b, Table A6). The objectives are based on the quantitative criteria used to estimate extinction risk for species (IUCN, 2016) and risk of collapse for ecosystems (Bland et al., 2017). Thus, an evaluation of goal achievement can be carried out through assessing the Red List category of the RLO (see details in Tables A4 and A5) in the target year. For example: to downlist a species categorized as Critically Endangered to Endangered by criterion A2, the objective should be stated as a reduction in the rate of decline of reproducing individuals to $<80\%$ (i.e. A2 threshold for category Endangered) by the target year. All Red List criteria are evaluated in the same way. A ‘business as usual’ scenario is stated specifically for each Red List criterion (objective) (Table A6) and defined as the projected Red List status of the RLO in the target year, given the continuation of existing conservation actions, and without the implementation of new actions. Information about timing, scope and severity of the identified threats in the Red List is used as the basis for describing the business as usual scenario.

2.1.3. Identify conservation actions

Conservation actions (point 3 in Box 1, Tables A7–A9) are defined as any action taken in order to increase (or abate the reduction of) population sizes of species or improve the degradation state of habitat, and increase the number of locations or area of occupancy of the RLO (cf. the Red List criteria). Conservation actions can be e.g. ex situ conservation,

Box 1
Red to Green framework. Overview of the steps for producing assessments for conserving Red Listed species and habitats.

1) Collect data
   a. Summarize knowledge of the distribution, ecology, taxonomic status/habitat condition, etc., including a description and evaluation of current knowledge status of the Red List Object (RLO), including both species and habitats.
   b. Provide the current Red List status of the RLO, i.e. distribution, population size, Red List category.
   c. Identify and characterize the extent of factors with negative impact on the RLO (threats).
2) Set goals
   a. Set a conservation goal for the RLO in terms of an improvement of the Red List category to be achieved by a target year.
   b. Use the Red List criteria to set specific objectives: specify threshold value for each variable included in the Red List criteria (e.g. population size) that is critical to reach the RLO's conservation goal.
   c. Describe a business as usual scenario: an anticipation of the RLO's development until a pre-defined target year, if no new (i.e. except ongoing) conservation actions for improving the RLO status were to be implemented.
3) Identify conservation actions
   a. Describe all possible actions that can contribute to achieving the goal. Assess the costs of implementation. Assess whether the action, if implemented alone, is likely to achieve the conservation goal.
   b. Combine conservation actions in action portfolios that when implemented together, are likely to achieve the conservation goal. Assess level of achievement. Assess action portfolio costs.
   c. Recommend action portfolio, based on an evaluation of the costs and the likelihood of success. In cases when knowledge gaps hinder a full assessment, recommended projects that would cover the necessary data collections that could lead to a recommended action portfolio in the future.

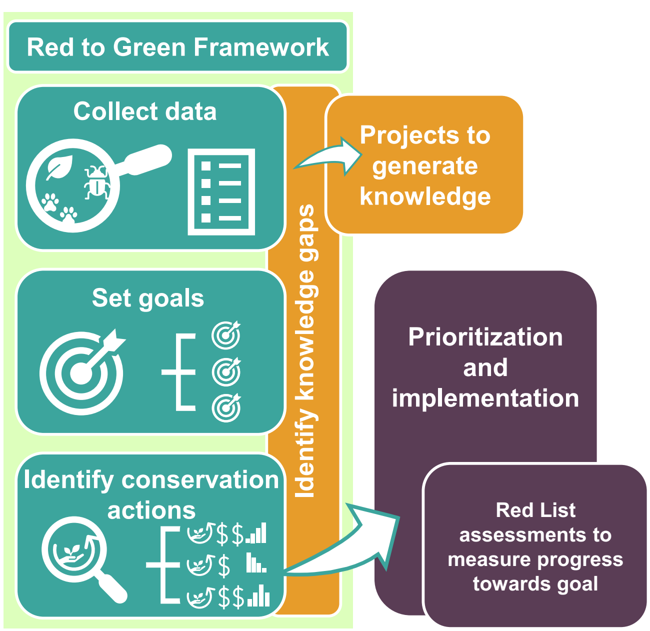

Fig. 1. The Red to Green framework has three main steps for assessing Red Listed species and habitats (Red List Objects, RLO) in order to identify and recommend conservation actions. For details on methodology, see Box 1 and main text. The first step is to collect data. Basic knowledge of the RLO is extracted from literature. The knowledge status is assessed, and knowledge gaps may be identified, for example on occurrence and distribution, life-history traits or effect of conservation action. For RLOs where knowledge gaps are a barrier to identify or recommend actions, projects to generate knowledge may be suggested. The second step is to set goals. A main goal is defined as a change in Red List category and measurable objectives are set using the Red List criteria. The third step is to identify conservation actions. All possible actions that counteract threats to the RLO are identified. Actions are combined in action portfolios and the likelihood of achieving the goal is assessed and the cost of implementing the actions calculated. The outcome of the assessments forms a basis for prioritizing and implementing conservation action to bend the curve on biodiversity loss. The progress towards the goal can be measured through Red List assessments. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

captive breeding, habitat management and/or habitat protection (cf. Salafsky et al., 2008).

All relevant conservation actions for a given RLO are identified. An identified conservation action should specifically address one or several threats (e.g. logging and wood harvesting), and also one or several objectives – e.g. increasing the number of reproducing individuals (cf. example above) and be described in detail, including the extent it should cover (area, proportion of populations, number of occurrences, etc.), the methods used (e.g. mowing or grazing, methods for removal of invasive alien species), and the timing and recurrence (e.g. in spring or summer, and once, annually or every 5th year).

The anticipated level of achievement, defined as the probability of achieving the addressed objective for the RLO by the conservation action, is assessed based on a combination of expert opinion and available data of specific action effects (e.g. Sutherland et al., 2019), using e.g. categories of 0–25%, 25–50%, 50–75%, and 75%–100% (see Tables A7–A9).

Conservation actions are then combined into RLO-specific action portfolios (Box 1, point 3b), i.e. sets of actions that together address all objectives and threats. The anticipated level of achievement (of the conservation goal), is assessed for the portfolio based on the anticipated level of achievement assessed for single conservation actions (see Tables A7–A9).

The costs to implement conservation actions are calculated; for each action separately and for each specified action portfolio, using information on number and size of sites, and the cost of actions (establishment, recurrence, maintenance etc.). The uncertainty of the cost estimates is assessed, based on available knowledge (see Appendix A for details).

Finally, one action portfolio is recommended for implementation for each RLO. Recommended action portfolios have a high probability of achieving the conservation goal, e.g. > 75%, as a low level of achievement suggests uncertain effects of implementing the action portfolio.

If existing data are insufficient to recommend conservation action portfolios with high level of achievement, the framework describes how to identify the data needed to make such a recommendation, such as mapping species distributions or monitoring effects of actions (point 3c in Box 1, see also Table A10). This is critical as the data needed to assess the risk of extinction of species and collapse of habitats by using the Red List criteria, could be less detailed than the data needed to identify conservation actions and estimate effects of actions. An important part of the compilation of the Red to Green assessments is thus to identify knowledge gaps.

2.2. Norway national case study

The framework was tested on a dataset of 123 RLOs, which included 90 species and 33 habitats, following the prioritization of the Norwegian NBSAP (Norwegian Ministry of Climate and Environment, 2015). Consequently, the case study included species with i) > 25% of the European population within Norway that are ii) classified as Critically Endangered or Endangered in the Norwegian Red List for species (Henriksen and Hilmo, 2015a). The habitats included those listed as threatened (Critically Endangered, Endangered, or Vulnerable) or Near Threatened according to the Norwegian Red List for ecosystems and habitat types (Lindgaard and Henriksen, 2011), in addition to two habitats of particular management interest assessed as Least Concern. The Norwegian Red List for habitats follows the IUCN guidelines for Red List categories and criteria for ecosystems (Bland et al., 2017), but extinction risk is evaluated for finer habitat typology (nature types or habitats) than ecosystems.

The Norwegian Environment Agency specified the conservation goal for this project according to the NBSAP: to downlist all RLOs by one Red List category by 2035. A group of experts including biologists and economists with scientific knowledge of the RLOs and of cost assessment calculations of conservation actions, was established, including 25 biologists and three economists. Assessments were completed in 2018.

Experts used the threat scheme of the Norwegian Red Lists, an adaptation of the IUCN threat scheme to Norwegian conditions (Ødegaard et al., 2005; Henriksen and Hilmo, 2015b). For RLOs for which the conservation goal of downlisting by one Red List category was evaluated as either being easily achievable or impossible/extremely difficult to achieve, an alternative "adjusted goal" was set. Such adjusted goals could be, for instance, "downlisting by two categories" or "no deterioration in category", by 2035. Based on the framework described above, conservation actions and action portfolios were identified, and the level of achievement was specified for each action if implemented alone, and for each action portfolio. At the current stage, spatial definition of each action was not defined (see Discussion, where framework improvements are considered).

The costs of actions were estimated using standard assumptions in cost analyses and according to official national guidelines (Norwegian Ministry of Finance, 2014, Norwegian Agency for Public and Financial Management, 2018). We included direct costs such as materials and equipment (e.g. fences) and work hours (e.g. for mowing), as well as indirect costs of protecting land. The present value was calculated using a standard discount rate of 4% to project the cost in the period 2018–2035. For very comprehensive actions, e.g. land protection, reducing greenhouse gas emissions or nitrogen deposition, costs were not estimated but assigned to a cost category to indicate the order of magnitude (see example in Appendix A). Calculated costs are hereafter referred to as «calculated», while costs assigned to cost categories are referred to as «assessed». The costs, and estimates of cost uncertainty, were determined for all actions and all action portfolios.

The anticipated level of achievement for each conservation action was assessed by the expert, based on existing literature. This was used to evaluate the overall achievement of implementing action portfolios. The action portfolio with minimum cost and a level of achievement >75% was recommended for implementation to reach the goal (Box 1, see Appendix A for details).

2.2.1. Constraints in conservation outcome

It was evident when using the Red to Green framework that knowledge gaps posed considerable limitations to proposing relevant conservation actions and project outcomes. It was also evident that experts reduced rather than increased the project's ambitions when they determined an adjusted goal for each RLO after considering the project's "opportunity space", for example, this could be to identify conservation actions that abate the effect of climate change. Therefore, we quantified the extent to which knowledge gaps and limitations in the project's "opportunity space" would constrain the anticipated conservation outcome, i.e. the predicted improvement in the RLOs conservation status, if these constraints remained unaddressed or unresolved.

Quantifying such effects allowed the assessment of the value of increasing knowledge and/or the opportunity space through for instance, international or regional coordination of actions. It also allowed us to further explore: what type of new knowledge would have contributed most in order to improve the outcome; which threat categories were difficult to counteract or compensate for through conservation actions; how much each threat category limited the potential outcome; and how much the proposed actions contributed to the outcome. In the next paragraphs, in Tables 1 and 2, and in Appendix B we explain how we addressed these questions.

2.2.2. Calculation of anticipated conservation status and outcome

We used the revised version of the Red List Index (*RLI*, Butchart et al., 2007, Table 1) to measure the average conservation status of the habitats and species included in the case study. To establish the current status of habitats, we calculated the *RLI* for the set of habitats based on their Red List assessments in the Norwegian Red List for ecosystems and habitat types of 2011 and 2018 (Lindgaard and Henriksen, 2011; Norwegian Biodiversity Information Centre, 2018). For the set of species, we calculated the *RLI* for the years 2006, 2010 and 2015 based on their classifications in the national Red Lists for Norway (Kålås et al., 2006, 2010; Henriksen and Hilmo, 2015a). Details of these calculations, including how we treated missing classifications in older Red Lists, are provided in Appendix B.

In order to estimate the *average* conservation status of habitats and species by 2035, we calculated the *RLI* for the set of habitats and the set of species under each of four potential scenarios. For our purposes, the following scenarios were relevant: the Original Ambition scenario (*oa*), Adjusted Ambition scenario (*aa*), Estimated Effect scenario (*ee*), and Business as Usual (*bau*). These scenarios are described in detail in Table 2.

We then calculated the *summed* conservation status of the set of species and the set of habitats, that we defined as $C = n * RLI$, where n is the number of RLOs in the set, and C ranges between 0 and n. The summed conservation status was used to calculate anticipated conservation outcomes (ΔC, Table 1), i.e. the difference in conservation status between alternative scenarios at the end of the project period in 2035.

The total anticipated conservation outcome associated with the project's original goals (ΔC_{tot}), and the potential outcome of implementing all recommended action portfolios successfully (ΔC_{ce}) corresponded to the differences in conservation status between scenarios *oa* and *bau*, and between *ee* and *bau* respectively (Table 2). Thus, the anticipated conservation outcome was measured in terms of reductions in extinction risks associated with project goals and the implementation of recommended action portfolios. To estimate the anticipated loss in the project's conservation outcome due to insufficient knowledge, we calculated the difference between conservation status under scenarios *ee* and *aa* (ΔC_{kn}, Table 2). To estimate the net loss in conservation outcome relative to the project's original ambition, that was due to limitations in project scope or opportunity space, we calculated the difference in conservation status under scenarios *aa* and *oa* (ΔC_{ra}, Table 2).

2.2.3. Relationship between threat- and knowledge gap categories and anticipated conservation outcome

We used documentation of threats to species and habitats (see Table B4 and B5 in Appendix B) to estimate how much each threat category contributed to the anticipated losses and gains in conservation outcome by 2035. The formula for calculating the contributions is provided in Table 1. It is based on the relative contributions from each threat category to the extinction risk of each RLO (R). Extinction risk

Table 1
Indices used to measure conservation status and conservation outcome with respect to extinction risks among a set of Red List objects (RLOs).

	Symbol	Definition	Explanation
Red List category weights	w	(Regionally) Extinct: w = 5, Critically Endangered: w = 4, Endangered: w = 3, Vulnerable: w = 2, Near Threatened: w = 1, Least Concern: w = 0	Numerical representation of Red List categories based on an 'equal steps' scale (cf. Butchart et al., 2007).
Red List Index	RLI	$RLI = \frac{w_{max} - \overline{w}}{w_{max} - w_{min}}$ $RLI = 1 - \frac{\sum_{i=1}^{n} w_i}{w_{max} n}$	Min-max normalized difference between the maximal Red List category weight ($w_{max} = 5$) and the average weight for the set of n RLOs ($\overline{w} = \sum_{i=1}^{n} w_i / n$), where $w_{min} = 0$ (cf. Butchart et al., 2007). *RLI* ranges between 0 and 1 where 0 corresponds to all RLOs being regionally extinct or completely degraded, while 1 indicates that no RLOs are threatened according to Red List criteria. *RLI* is used to measure the average conservation status of a set of RLOs.
Conservation status	C	$C = \frac{\sum_{i=1}^{n} (w_{max} - w_i)}{w_{max}}$ $C = n * RLI$	Sum of min-max normalized differences between the maximal Red List category weight and the weight for each member of a set of RLOs. C ranges between 0 and n, where n is the number of RLOs in the set. C is used to measure the summed conservation status of a set of RLOs. $C = n - \frac{T}{w_{max}}$, where T is the so called Threat Score defined in Butchart et al. (2007).
Conservation outcome	ΔC	$\Delta C = C_j - C_k$ $\Delta C = \frac{\sum_{i=1}^{n} (w_{i,k} - w_{i,j})}{w_{max}}$	The difference in summed conservation status between two scenarios j and k where $w_{i,\ j}$ is the weight associated with the Red List category for RLO i under scenario j (cf. Table 2). ΔC may be both positive and negative. A positive outcome means that scenario j represents a gain in status relative to scenario k, while a negative outcome means that scenario j represents a loss relative to k.
A partition of conservation outcomes into effects of threat categories	ΔC_t	$\Delta C_t = \frac{\sum_{i=1}^{n} R_{i,t} (w_{i,k} - w_{i,j})}{w_{max}}$	$R_{i,\ t}$ is the relative contribution of threat category t to the extinction risk of RLO i (cf. Appendix B). $\sum_{t=1}^{n_t} R_{i,t} = 1$, n_t is the number of threat categories, and $\sum_{t=1}^{n_t} \Delta C_t = \Delta C$.
A partition of negative conservation outcomes into effects of knowledge gap categories	ΔC_K	$\Delta C_K = \frac{\sum_{i=1}^{n} Q_{i,K} (w_{i,k} - w_{i,j})}{w_{max}}$	$Q_{i,\ K}$ is the relative effect of knowledge gap category K to the potential loss in conservation outcome associated with RLO i. $Q_{i,K} = \frac{1}{q_i}$ if there was a gap, $Q_{i,\ K} = 0$ if not. q_i is the number of categories where knowledge is considered insufficient to suggest conservation actions for RLO i. $\sum_{K=1}^{n_K} \Delta C_K = \Delta C$.

contributions were estimated from threat scope and severity information provided by the experts in point 1c (Box 1) of the methodology. The calculation is described in more detail in Appendix B.

Specifically, for each threat category t we quantified first the anticipated loss in conservation outcome when knowledge gaps prevented experts from recommending conservation actions that reduce the extinction risk posed by the threat ($\Delta C_{kn,\ t}$). Second, we quantified the anticipated net loss or gain in conservation outcome when experts used an adjusted goal for RLOs exposed to the threat ($\Delta C_{ra,\ t}$). Third, the anticipated conservation benefit of recommended actions against the threat ($\Delta C_{ce,\ t}$) was calculated. Calculations were done by partitioning the three conservation outcomes into effects of each threat category, i.e. $\sum_{t=1}^{n_t} \Delta C_{kn,t} = \Delta C_{kn}$, $\sum_{t=1}^{n_t} \Delta C_{ra,t} = \Delta C_{ra}$, and $\sum_{t=1}^{n_t} \Delta C_{ce,t} = \Delta C_{ce}$(cf. Table 1), where n_t is the number of threat categories.

In a similar manner, we partitioned ΔC_{kn} into effects of knowledge that experts identified as missing, whether it concerned: taxonomy; RLO's distribution and occurrence; their life history, habitat, or niche; population structure and dynamics; ecosystem state; threats; or effect of potential conservation actions. In this way we described how gaps in each of these categories of knowledge potentially reduced the possibilities for obtaining the total, anticipated conservation outcome that lay in the original ambition for the project.

3. Results

3.1. Norway national case study

The case study included seven organism groups: fungi (13), bryophytes (7), lichens (18), vascular plants (34), invertebrates (12), fish (2), and mammals (4) (Table B5). The habitats covered both marine (6), freshwater (4) and terrestrial (23) ecosystems (Table B4). The original goal of downlisting species and habitats by one Red List category was applied to 69 species and 25 habitats. An adjusted goal of downlisting by two categories was proposed for one species and one habitat. For the remaining 37 RLOs an adjusted goal of no change in Red List category by 2035 was applied (Tables B4 and B5).

Land-use change was by far the largest threat to both species and habitats (Fig. 2a). For about 25% of the RLOs, mainly alpine/arctic vascular plants, climate change was the main threat. Conservation actions were suggested for 74 species and 26 habitats, but for 60 species and seven habitats, sufficient knowledge was lacking on e.g. distribution ranges, current occurrences, impact of threats and the effect of actions, in order to recommend conservation actions with a level of achievement

Table 2
Anticipated conservation status (C) and outcome (ΔC) by 2035 according to four scenarios of conservation actions for sets of 33 red listed habitats and 90 red listed species (RLOs). The anticipated conservation gains and losses were estimated by comparing the status under different scenarios.

Scenarios				
Name	Symbol	Explanation	C habitats	C species
Original ambition	*oa*	Scenario corresponding to fulfilling the project's original goal that all Red List Objects (RLOs) by 2035 should have a reduced extinction risk of one Red List category each.	24.4	50.6
Adjusted ambition	*aa*	Scenario corresponding to fulfilling the revised goals set by the experts after they evaluated the opportunity space that existed within the project's framework.	23.4	46.6
Estimated effect	*ee*	Scenario corresponding to the conservation status in 2035 if all recommended conservation action portfolios are implemented successfully, while no actions are implemented for RLOs where knowledge gaps prevented experts from recommending action portfolios.	22.2	37.5
Business as usual	*bau*	Scenario corresponding to the experts' estimate of the RLOs' status in 2035 if no new conservation actions are implemented after 2018.	17.4	31.6
Anticipated gains and losses in conservation outcome				
	Definition	Explanation	ΔC habitats	ΔC species
Total conservation outcome	$\Delta C_{tot} = C_{oa} - C_{bau}$	Anticipated, total conservation outcome associated with the project's original goal. $\Delta C_{tot} = \Delta C_{ce} - \Delta C_{ra} - \Delta C_{kn}$.	7.0	19.0
Revised ambitions	$\Delta C_{ra} = C_{aa} - C_{oa}$	Conservation loss or gain due to adjusted goals. It represents the change in potential conservation outcome, relative to the original ambition, when experts adjust the goal for each RLO after considering the opportunity space that exist within the project's framework. ΔCV_{ra} may be negative or positive.	−1.0	−4.0
Knowledge gaps	$\Delta C_{kn} = C_{ee} - C_{aa}$	Anticipated loss ($\Delta C_{kn} < 0$) in conservation outcome due to insufficient knowledge base to propose actions that fulfil the adjusted ambitions.	−1.2	−9.1
Conservation actions	$\Delta C_{ce} = C_{ee} - C_{bau}$	The potential conservation benefit of implementing all recommended action portfolios successfully	4.8	5.9

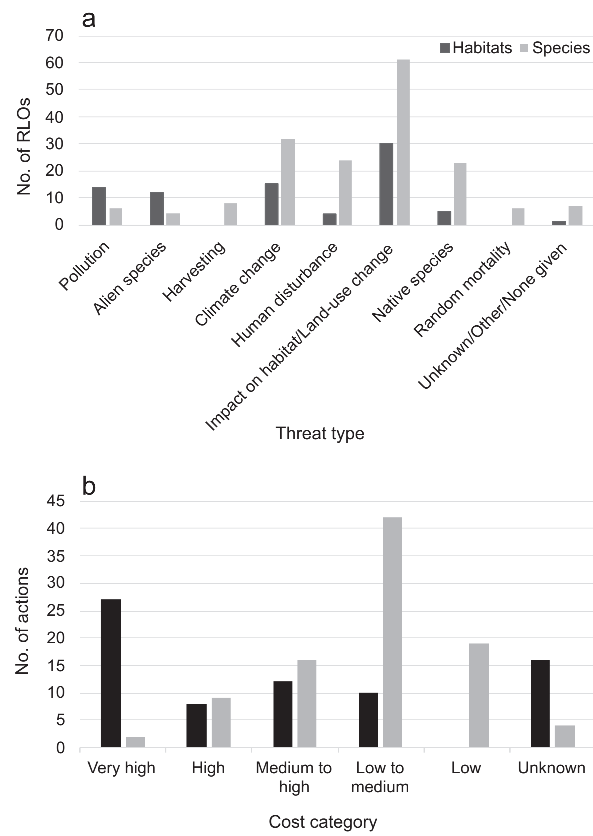

Fig. 2. The histograms show (a) the number of Red List Objects for each threat category given at the highest hierarchical level in the Norwegian threat scheme (Ødegaard et al., 2005) and (b) the cost category for each conservation action recommended to be implemented through an action portfolio. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

>75%. Consequently, conservation action portfolios were only recommended for 30 species and 26 habitats.

A total of 166 conservation actions were identified in all recommended action portfolios combined. Land protection, i.e. set-asides, was the most frequently suggested conservation action, followed by ex situ conservation and habitat management for species, and restoration and habitat management for habitats. Costs were calculated for 58% of actions, while the remaining 42% actions were assigned to a cost category. Conservation actions targeted towards species were generally cheaper than for habitats, and a larger proportion of actions towards habitats had unknown costs (Fig. 2b).

3.2. Anticipated conservation outcomes in Norway

The original project goal implied a considerable improvement in average conservation status of the sets of habitats and species, as measured by the *RLI*, compared to the Business as Usual (*bau*) scenario (Fig. 3). If no new conservation actions were to be implemented (*bau*), the status of both sets was anticipated to be lower in 2035 than in 2011 (for habitats) and 2015 (for species).

However, limitations in the project's "opportunity space" and knowledge gaps reduced the anticipated conservation outcome. The conservation outcome for the Adjusted Ambition scenario was lower than the outcome set by the original project goals, by 21% and 14% for species and habitats, respectively. The main reasons for the reduced outcomes were the inability to abate the negative impacts of climate change on species and of land-use change on habitats (Fig. 4).

The anticipated conservation gain in 2035 of implementing all

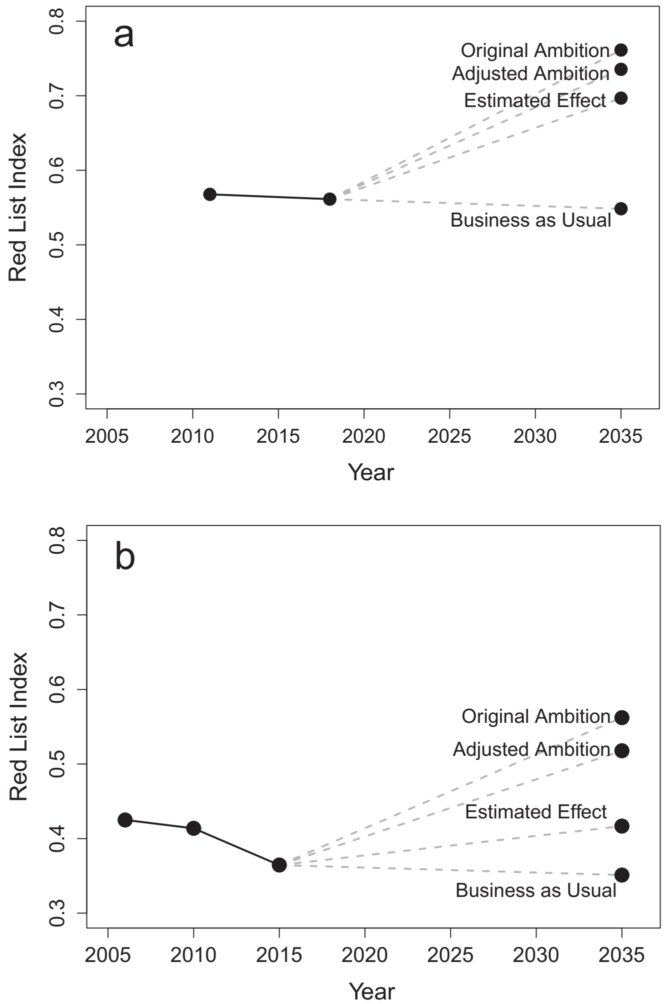

Fig. 3. Red List Index for (a) habitats and (b) species included in the test dataset according to national Red Lists for Norway and four scenarios of conservation actions projected to be implemented by 2035. The "Original Ambition" scenario corresponds to the project's original goal that all Red List objects (RLOs) should have a reduced extinction risk of one Red List category by 2035. "Adjusted Ambition" is the revised ambition after evaluating the opportunity space given within the project's framework. The "Estimated Effect" scenario is the state of RLOs in 2035 if all recommended conservation action portfolios are implemented successfully, while "Business as usual" is based on the experts' estimate of state in 2035 if no new conservation actions are implemented after 2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

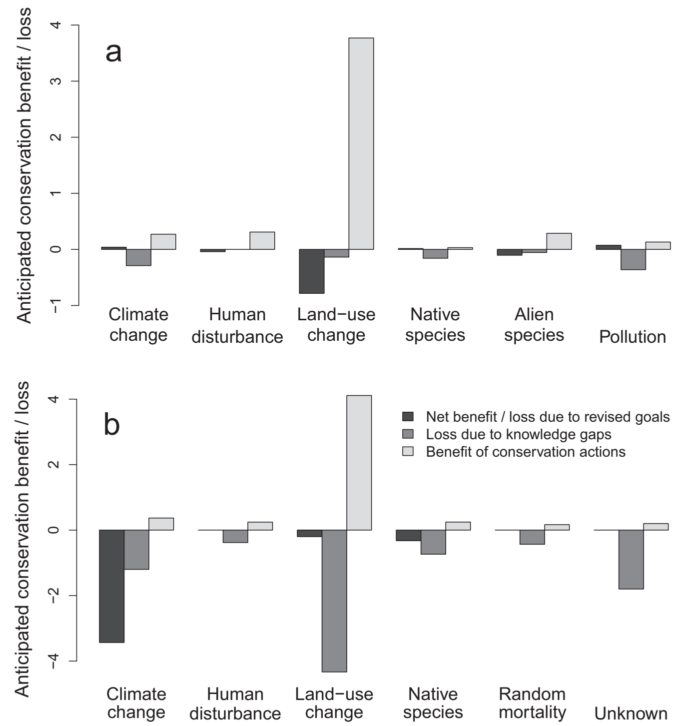

Fig. 4. Potential conservation benefits and losses associated with the six most influential types of threat categories to (a) habitats and (b) species. Light-grey columns represent the anticipated conservation benefit of implementing all recommended conservation action portfolios successfully, black columns represent net conservation loss or benefit due to adjusted goals, while dark grey columns show anticipated loss due to an insufficient knowledge to propose conservation actions.

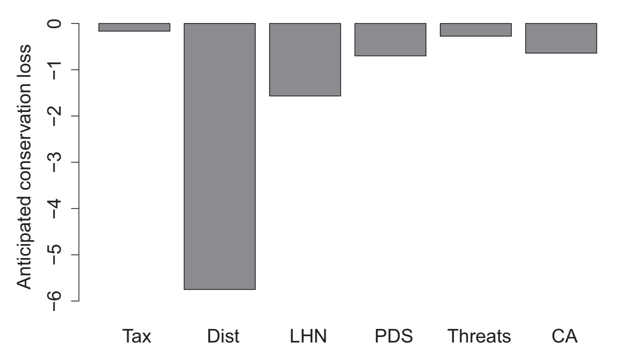

Fig. 5. Anticipated conservation losses for species due to lack of knowledge about their taxonomy (Tax), their distribution or occurrence (Dist), their life history, habitat or niche (LHN), their population structure and dynamics (PDS), threats they are exposed to, or the effect of possible conservation actions (CA).

recommended conservation portfolios successfully (ΔC_{ce}), was for species only 31% of the gain set by the original ambition (ΔC_{tot}), but substantially higher for habitats (69%; Table 2). Thus, knowledge gaps were a larger challenge for species than for habitats (Table 2).

Restricted opportunities (Adjusted Ambition scenario) were the main reasons for low conservation outcome for species threatened by climate change. Knowledge gaps prevented experts from suggesting conservation actions, especially in the case of species threatened by land-use change, but also for other threat categories (Fig. 4). Lack of data on species distributions and occurrences was the main type of knowledge gap preventing experts from suggesting conservation action for species (Fig. 5). For habitats, land-use change was by far the most important threat category, and actions counteracting the impact of land-use change yielded high conservation benefits (Fig. 4).

4. Discussion

The Red to Green framework that we present operationalizes national Red Lists as a tool to plan conservation actions strategically to halt biodiversity loss. The framework allows for flexible conservation goals, e.g. a goal of downlisting (our case study) or species recovery (Akçakaya et al., 2018), and flexible time frames, depending on national strategies (Mace et al., 2018). Testable objectives are a prerequisite for measuring progress towards achieving the goals. By linking conservation goals to specific, quantifiable objectives based on the criteria of the IUCN Red Lists, regular Red List assessments will reveal whether objectives are achieved, and species and habitat conservation statuses are improved. This allows for evaluation and reporting of targets as set by NBSAPs and international agreements.

4.1. Bending the curve at the national level: the Norwegian case study

The assessments of RLOs rely on critical data and information, compiled from scientific and grey literature by experts (cf. Akçakaya et al., 2018; Brazill-Boast et al., 2018; Sutherland et al., 2019). We tested the framework on a large set of species and habitats, covering marine, freshwater and terrestrial ecosystems, and a range of taxonomic groups with different ecology and life-history, as well as varying knowledge status, all prioritized in the Norwegian national action plan for biodiversity (Norwegian Ministry of Climate and Environment, 2015). Applying the framework to this varied set of RLOs allowed in the identification of those RLOs that are suitable to target for improved conservation status through conservation actions, i.e. with sufficient knowledge and abatable threats. This is an important first step for planning conservation efforts strategically, which is often implicit in prioritization protocols (e.g. Brazill-Boast et al., 2018). However, our case study dataset did not allow for joint considerations of conservation action benefits for sets of species/habitats, as the species included were all extremely rare, and many confined to alpine and arctic habitats, which were not considered to be threatened in the 2011 Red List of habitats (Lindgaard and Henriksen, 2011). Thus, there was low spatial overlap between occurrences of assessed species, and between species and assessed habitats, despite several of the threatened habitats being hotspots for nationally threatened species (e.g. Evju et al., 2015; Olsen et al., 2018). Red to Green assessments can help to identify these patterns, and inform priority setting and targeting of conservation actions.

The calculation of the potential conservation outcome allowed us to explore barriers to bending the curve. Following the roadmap suggested by Mace et al. (2018), our analyses were based on a set of conservation goals, scenarios for the situation in 2035 (Ferraro, 2009), and simple, index-based metrics (Butchart et al., 2007). The analyses revealed which threat categories are difficult to counteract through conservation actions, and how much the proposed actions contributed to the outcome (Fig. 4). We demonstrate that the goal of bending the curve of biodiversity loss in Norway is possible to reach, although very challenging. However, our analyses identified two main barriers.

First, for about 30% of RLOs, mainly species, an adjusted conservation goal was formulated, indicating that no change in Red List category was possible within the given time frame (2035). Climate change is a significant threat to biodiversity, in particular to many arctic and alpine vascular plants. For these species our case study identified ex situ conservation as the most relevant action. However, ex situ conservation is an action to avoid extinction, rather than to improve conservation status. Hence, in the absence of conservation actions to improve conservation status, experts instead reduced the ambitions (no deterioration of conservation status by 2035). For Norway to be able to reach national biodiversity targets, our findings thus highlight the extreme importance of international cooperation to reduce global warming. Similarly, for three marine mammals, the implementation of conservation actions calls for international cooperation, as these animals move across larger geographical scales than assessed in the Norwegian Red List.

Second, our results showed that for two-thirds of species and one-fifth of habitats there was insufficient knowledge to suggest or implement conservation actions. Thus, knowledge gaps posed considerable limitations on conservation outcome, particularly lack of basic information on species' distributions and occurrences, but also knowledge of their ecology and life-history. Increasing knowledge therefore appears necessary to suggest conservation actions for many threatened species (see also Fitzpatrick et al., 2007), and we show that reducing such knowledge gaps through data collection would hugely increase the opportunities to gain conservation benefits. For national conservation goals to be fulfilled, actions to increase such knowledge should be prioritized when feasible (McDonald-Madden et al., 2010). However, the benefits gained through additional knowledge generation needs to be weighed up with the cost of obtaining such information, and how it compares to the cost of conservation actions. If species are likely suffering from threats that are difficult for a country to tackle alone, such as climate change, then knowledge generation is unlikely to lead to improvements of national conservation goals. Therefore, the costs and potential outcomes of knowledge generation need to be compared with actions that can be taken for RLOs with the information that is already available. Existing methods such as Value of Information (Runge et al., 2011; Nicol et al., 2019), could be applied to evaluate this trade-off.

4.2. Knowledge gaps

Norway is a country rich in resources but relatively poor in biodiversity. National Red Lists are regularly updated and include most taxonomic groups. Even so, we identified knowledge gaps as a barrier to bending the curve on biodiversity loss through targeted conservation interventions. This is likely also the case in other countries (e.g. Gaulke et al., 2019). A systematic review of the knowledge status of RLOs is thus an important first step, but not necessarily an obstacle to suggest actions. Red to Green assessments of RLOs can reveal if existing knowledge is sufficient to recommend conservation actions. In some cases, knowledge gaps constrain the opportunity to suggest and implement actions, but in other cases they do not. The Norwegian case study included many data-poor species (for example, an insect known from only one location), yet despite this, our analysis revealed a high conservation benefit of actions targeting land-use change, particularly for habitats. This suggests that, at least in broad terms, knowledge of relevant conservation actions and their effects on habitats is available. Databases such as the IUCN Red List of species (Mace et al., 2008) contain the baseline ecological information necessary to support application of the Red to Green framework across multiple taxonomic groups globally, and the Red List can be used to quantify the relative contribution of different threats to species' extinction risk (Mair et al., 2021). Further, in species rich areas, conservation actions to preserve habitats would likely benefit several species, even though knowledge gaps on species' life history and occurrences exist. Through application of the Red to Green framework, the benefits in terms of conservation outcome gained through additional knowledge generation can be quantified (see Fig. 4).

The outcomes of conservation actions are not routinely monitored in Norway, and no national database exists describing conservation actions (methods, location, target species/habitat), their costs or their outcomes. Likewise, such data are frequently lacking internationally (Arponen, 2012), although extensive databases are being built for this purpose (Sutherland et al., 2019). Hence, we largely used expert opinion both for suggesting conservation actions and assessing their potential success in terms of improving conservation status, as in similar protocols (e.g. Brazill-Boast et al., 2018; Carwardine et al., 2019). This was also the case for assessment of costs, in which expert opinions and large uncertainties prevailed. Uncertainty around the impacts and costs of conservation action could decrease the effectiveness of prioritized conservation plans (Brazill-Boast et al., 2018; Cattarino et al., 2018; Nicol et al., 2019). Nevertheless, costs and potential outcomes of knowledge generation need to be compared with actions that can be taken for the RLOs with the information already available (Runge et al., 2011).

4.3. Future developments of the Red to Green Framework

The proposed Red to Green framework includes critical steps for the implementation of international biodiversity goals on a national scale. Several aspects in the framework could be improved in future use. Foremost, to identify conservation actions that explicitly counteract a threat, it is crucial to know how species and habitats respond to threats and conservation actions. Cost-effectiveness is routinely calculated in prioritization protocols (Joseph et al., 2009; Brazill-Boast et al., 2018), as conservation benefit (estimated effect) multiplied with likelihood of success/level of achievement, divided by estimated costs. However, in addition to the benefit of reducing extinction risk of the RLO in question, additional benefits of conserving habitats or species should be incorporated in extended cost-benefit analyses. For example, preserving habitats not only affects species on the Red List, it may also contribute to maintaining ecosystem processes and robust ecosystems, establishing a network of green corridors, and reducing the risk of additional species becoming threatened. Furthermore, nature provides substantial services to humanity, such as carbon sequestration, reduced risk of natural disasters, and sustaining pollinating services in agriculture. Analyses show that societal benefits of conservation actions, e.g. habitat restoration, may exceed costs (Glenk and Martin-Ortega, 2018). Unfortunately, such analyses are rarely incorporated in conservation planning (Brazill-Boast et al., 2018; Carwardine et al., 2019). We suggest that in further developments of the Red to Green framework, societal costs and multiple benefits are highlighted to facilitate resolving trade-offs between conservation actions and other societal interests (Glenk et al., 2014), and to inform in prioritization of actions (Schröter et al., 2017).

For efficient project planning and prioritization, spatial targeting of conservation actions is critical, ensuring that the right threats are abated in the right places. This is an important next step for the use of our framework in a planning process. Spatially explicit data also facilitate the identification of synergies of actions needed by different RLOs and might allow for a threat management approach (cf. Carwardine et al., 2019) that may increase cost-efficiency even further (Schröter et al., 2017). A joint evaluation of multiple species and habitats allows the development of genuinely strategic conservation plans for biodiversity (Brazill-Boast et al., 2018; Strassburg et al., 2020). Our case study dataset did not allow for identifying synergies of conserving a range of RLOs, but the framework forms a basis to do so and next to make prioritizations. By identifying spatial occurrences of RLOs, their habitat requirements and specialization (for species), and concrete conservation actions, a systematic analysis of potential synergies and trade-offs is possible. Such analysis would allow us to answer various questions, including:

- In which habitats, ecosystems or geographic areas would a given conservation action benefit most species, or most sub-populations of a given set of species?
- Is a given conservation action recommended for all threatened species in a habitat, or may it be counteractive to some species and/or would additional species-specific actions be needed?
- Could we carry out conservation actions at the habitat level (i.e. general habitat management or restoration) and expect to benefit the species within that habitat sufficiently to meet conservation goals for all species, or are species-specific actions a necessary supplement?
- Which conservation actions yield the highest anticipated probability of success for the most RLOs, whilst having the lowest costs?

4.4. Final recommendations

We tested the Red to Green framework on a prioritized list of species and habitats from the Norwegian NBSAP. Our results show that this may not be the best starting point for designing a national conservation action plan. National planning of conservation efforts would be better informed by a more comprehensive analysis of nationally threatened species, that overlap in terms of habitat requirements and/or spatial distribution. This would allow the identification of actions that will benefit several RLOs at the same time. Thus, the benefits of implementing conservation actions for a large number of RLOs could be more evident if, for example, habitats or species hotspots, defined either as geographically defined areas or as given habitat types, were targeted (Carwardine et al., 2019). Next, the framework should be tested on a more comprehensive dataset to further explore applicability elsewhere and potential synergies of assessing spatially overlapping RLOs.

The post-2020 global biodiversity framework is under development (Secretariat of CBD, 2018, 2019, 2020b; Dinerstein et al., 2019; Erdelen, 2020). Systems to measure progress are needed, and mechanisms to translate overall global targets into national targets and action plans are required (Rounsevell et al., 2020). In this context, the framework presented here has the potential to support policy implementation. Through a systematic assessment of knowledge and a strategic analysis of conservation actions, a solid foundation for developing national action plans for biodiversity conservation is available, allowing for prioritization and implementation of conservation actions and reporting on progress. An important part of this is the building and maintenance of national and international databases of conservation actions (Sutherland et al., 2019), that allow for learning and increased efficiency of conservation. Quantifying conservation impacts through adaptive management and monitoring is thus a necessary part of conservation plan implementation. Even in rich countries such as Norway, databases of knowledge status of RLOs and effects of conservation actions are lacking, hampering the implementation of actions for a set of species already prioritized for conservation. We underline the need for coordinated plans for implementation of conservation actions to maximize the conservation outcome and minimize socioeconomic costs (cf. Brazill-Boast et al., 2018).

CRediT authorship contribution statement

BP, ME, MOK, KM, JB, KMV conceived this idea; BP, ME, MOK, KM developed the framework; BP developed the index; MOK made the graphical illustration; BP analyzed the data; all authors contributed in writing and text revisions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

A detailed description of how to assess all stages in the red to Green framework (Appendix A) and details on adjustments done to the Red List Index, included the data sets (species and habitats) used to calculate the index (Appendix B), are available online. Supplementary data to this article can be found online at doi:https://doi.org/10.1016/j.biocon.2021.109227.

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