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Towards the development of a management relevant index for invasive alien species: a pilot study

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Abstract

Van Dijk, J., Åström, J., Pilskog, H. E. 2012. Towards the development of a management relevant index for invasive alien species: a pilot study - NINA Report 876. 36 pp.

Alien species are a major threat to biodiversity and biological invasions are halted where possible, both at the international and at the national level and attempts are made to prevent new invasions. International agreements state that by 2020 invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment. Already before 2010 attempts have been made to develop indicators of invasion to assess progress against the targets.

In Norway, the Nature Index was developed as a framework for gathering and synthesizing scientific knowledge on the state of biodiversity in a particular ecosystem in a given area by using a set of indicators (e.g. species). In this pilot study we exploited the possibility to develop a similar framework on the state of invasive alien species in a particular ecosystem in a given area by developing the Invasive Alien Species (IAS) index. The test case used in this pilot study showed the feasibility of using the same framework as that of the Nature Index while adjusting the mathematical background applicable to IAS. Weighting and scaling of the indicators, here a subset of IAS representative for dominating and/or changing the natural biodiversity, were adjusted to reflect the impact of IAS on native biodiversity. Weighting and scaling of each indicator is based on the principal of ecological effect (i.e. the weight or importance a species has in the index) combined with its invasion potential (i.e. scaling for its ecological risk on natural biodiversity when expanding and increasing in population distribution resp. size) based on the systematic risk assessment published by the Norwegian Biodiversity Information Centre. While the Nature Index ranges between 0 and 1, with 1 referring to intact ecosystems and 0 to degraded ecosystems, a higher IAS index actually refers to a potential higher risk to natural biodiversity. A lower IAS index shows that invasions are halted, for instance through eradication programmes.

The proposed IAS Index is a framework for gathering and synthesizing the knowledge and monitoring data on the state of invasive alien species in a particular ecosystem in a given area. The proposed IAS Index allows for simple illustration on the state of invasive alien species. Both through graphical maps and easy readable figures changes in the state of invasive alien species can be presented.

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Sammendrag

Van Dijk, J., Åström, J., Pilskog, H. E. 2012. Utvikling av en forvaltningsrettet indeks knyttet til fremmede arter: en forundersøkelse - NINA Rapport 876. 36 pp.

Fremmede arter er en stor trussel mot biologisk mangfold og man prøver å unngå spredning og etablering av fremmede arter både nasjonalt og internasjonalt. En målsetning i de internasjonale avtalene er at man i 2020 skal ha identifisert fremmede arter og deres spredningsvektorer. Videre skal det være satt i gang kontrolltiltak for å hindre spredning av arter som er etablert i landet, sikre utryddelse av et antall fremmede arter, samt tiltak for å hindre at nye fremmede arter kommer inn i landet. Allerede før 2010 ble det gjort flere forsøk på å utvikle indikatorene for å måle om tiltakene lykkes i å hindre etablering og/ eller spredning av fremmede arter.

Naturindeks (NI) for Norge ble utviklet for å måle tilstand og utvikling av biologisk mangfold i våre hovedøkosystem. Indeksen baserer seg på den til enhver tid beste kunnskap om tilstanden av biologisk mangfold i økosystemene ved hjelp av indikatorer (f.eks. arter). I denne pilotstudien undersøker vi muligheten for å etablere en ny «fremmed art indeks» (dvs. Invasive Alien Species (IAS) index) basert på rammeverket til naturindeks, men justert metodisk slik at den sier noe om den samlede effekten av IAS på en romlig skala. Casestudien i denne rapporten viser at det er mulig å bruke det samme rammeverk som i Naturindeks, med en justering slik at den matematiske bakgrunnen er spesifikk for fremmede arter. I motsetning til NI, vil IAS øke med økende potensiale for økologisk risiko av de fremmede artene som er tilstede i et område. Verdien på IAS indeksen vil være et mål på økologisk risiko for de artene som inngår i indeksen i et gitt område. Vekting og skalering av hver enkelt indikator baserer seg på prinsippene for økologisk effekt (betydning for vekt en art får i indeksen) og invasjonspotensiale (skalering - betydning for økologisk risiko ved lave bestander) utviklet gjennom svartelista.

Den foreslåtte IAS indeks er et rammeverk for innsamling og samkjøring av kunnskap og overvåkingsdata om tilstanden av fremmede arter i et spesifikk økosystem i et bestemt område. IAS Indeksen tillater enkel illustrasjon på tilstanden av innvandrende fremmede arter. Både gjennom grafiske kart og lettleselig figurer kan indeksendringene presenteres.

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Contents

Foreword

The first edition of the Norwegian Nature Index was published in autumn 2010 and it documents overall trends for the state of major ecosystems throughout the country using a large number of species and ecosystem indicators. The Nature Index also provides a readily available overview of whether Norway is making progress towards its goal of halting the loss of biodiversity. Because alien species are a major threat to biodiversity, it is desirable to develop the Nature Index framework further and investigate whether the approach is also applicable for the documentation of trends of alien species in Norway. Within this pilot project, we use the framework of the Nature Index, while adjusting the underlying mathematical models to be realistic for alien species and discuss relevant international work in this area as well as the possibilities for future work to establish a Norwegian Invasive Alien Species Index. This pilot project was commissioned and financed by the Norwegian Directorate for Nature management.

Jiska van Dijk, 1 October 2012

1 Introduction

Alien species are a major threat to biodiversity (MA 2005). Biological invasions are halted where possible, both at the international and at the national level, and attempts are made to prevent new invasions. Several international acts, protocols and political decisions have been made and adopted, including the emphasis on eradication and prevention of biological invasions. Also Norway has implemented several measures against biological invasions in line with the obligations and commitments to the Convention on Biological Diversity (CBD).

During the tenth meeting of the Conference of the Parties to the CBD (October 2010, Nagoya, Japan), the Aichi targets were adopted and one of the 20 targets describes the invasive alien species. Target 9 states that by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment. Already before 2010 several attempts have been made to develop indicators of invasion (McGeoch et al. 2006) to assess progress against the targets. However, until now there have been very few examples of indicators of invasion that are based on a range of taxa, cover large spatial scales, assess temporal trends in invasions or consider impacts of invasive species (Genovesi et al, 2012).

In Norway, the Nature Index was developed as a framework for gathering and synthesizing scientific knowledge on the state of biodiversity in a particular ecosystem in a given area by using a set of indicators (e.g. species) (Certain et al. 2011). In this present pilot study on Invasive Alien Species index (IAS index), we exploit the possibility to develop a similar framework on the state of invasive alien species. We also discuss the different alternatives given by the International Union for Conservation of Nature (IUCN) to be used as indicators to assess progress against the 2020 targets (see Mace & Taylor 2007) relevant to Norway.

2 Relevant political processes and research

Definitions

In this report we have used the definition proposal given in McGeoch et al. (2006) (see also Table 1.) in which *alien species* is defined as a species present due to intentional or accidental introduction as a result of human activity (Richardson et al. 2000). An *invasive species* on the other hand is defined as a naturalized species that produce reproductive offspring in a very large numbers and are able to spread whereas *transformer species* is defined as a subset of invasive species that change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem (Richardson et al. 2000). Species with an invasive or transformer status are often quantified as Invasive Alien Species (IAS) (McGeoch et al. 2006). Because the focus of CBD is on impacts and on indicators assessing the impacts it is wise to lump the two invasive categories (i.e. *invasive* and *transformer*) together (Mace & Taylor 2007).

For the purpose of this pilot study, in which we want to assess the state of alien species for which reproductive offspring and population spread has been observed and monitored, we refer to Invasive Alien Species (IAS) as defined in McGeoch et al. (2006). It is essential to clarify this at this point to avoid misunderstandings later in the presentation of the IAS Index (Chapter 3 – 6) where we assume that the alien species are reproducing offspring, are spreading and transform ecosystems. As also pointed out by McGeoch et al. (2012), there is a lot of misinterpretation in the terms *invasion* and *alien* resulting in different lists and overviews which alien species are present in the different countries. It is beyond the scope of this project to discuss which species are alien and which species are not for Norway and which of them are invasive and which are not considered invasive. We therefore account to the species listed in the alien species database available at the Norwegian Biodiversity Information Centre (NBIC) (http://www.biodiversity.no/Article.aspx?m=173&amid=2578).

The definition used in the risk analyses on alien species in Norway (Gederaas et al. 2012, see also paragraph 'Relevant processes on indicator development in Norway' further down in this Chapter) is the definition used by IUCN (Table 1). This definition includes the wordings 'dispersal potential' and 'might survive and subsequently reproduce' which implies *the possibility to* have a negative impact on natural biodiversity. In this report we focus on alien species that *already are reproducing and spreading* and *already have done changes to an ecosystem*. In other words, the focus of this report further contributes to the assessment of trends of alien species that have already invaded and transformed natural biodiversity.

Table 1. *Definitions in invasion biology relevant to this work (Adapted from: McGeoch et al. 2006)*

Wording	Definition (Reference)
Alien	a species present due to intentional or accidental introduction as a result of human activity (Richardson et al. 2000)
Alien	species, subspecies, or lower taxon occurring outside of its natural range (past or present) with dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN 2000)
Alien	a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (CBD 2002)
Invasive	a naturalized species that produce reproductive offspring in a very large numbers and are able to spread (Richardson et al. 2000)
Transformer	a subset of invasive species that change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem (Richardson et al. 2000)

Political commitment
It is globally recognized that invasive species together with climate change, habitat change, overexploitation and pollution are the major drivers of biodiversity loss (MA 2005). For instance, over 50% of animal extinctions for which the cause is known, can be assigned to the occurrence of invasive species (Clavero & Garcìa-Berthou 2005).

Already within the Ramsar Convention (Convention on the protection of wetlands; adopted in 1971 and in force in 1975), the Bonn Convention (Convention on Migratory Species of Wild Animals; adopted in 1979 and in force in 1983) and the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats; adopted in 1979 and in force in 1982), special attention was given to strict control of the introduction of, or control of already introduced, exotic species detrimental to the natural biodiversity. In addition, the global community has committed to prevent and mitigate the impacts of invasive alien species and to monitor trends in invasion through the CBD (UNEP 2002). Furthermore, it was decided that by 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment (UNEP Decision X/38 CBD COP10, Aichi target nr 9, Nagoya, October 2010). As a response to the Aichi targets, the European Council endorsed the EU biodiversity strategy to 2020 (3103rd Environment Council meeting, Luxembourg, June 2011) in which target 5 describes several goals with regard to the IAS issue (i.e. 1: identification and prioritization, 2: priority species controlled or eradicated, 3: pathways managed to prevent new introductions and establishments). These goals are complementary to the overall objective of the 2020 headline target 'Halting the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, and restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss' (Communication from the Commission COM (2011) 244 final).

Besides the ratification of the Ramsar Convention and the Bonn Convention, Norway has also ratified the CBD convention and committed itself to the CBD goals (since 1993). In its Fourth National Report to the CBD in 2009 (http://www.cbd.int/doc/world/no/no-nr-04-en.pdf), Norway reports that a cross-sectorial strategy on invasive alien species was finalized in 2007 (see Norwegian Ministry of Environment 2007). The Norwegian government also came forward with The Government's Environmental Policy and the State of the Environment in Norway (Report No. 26 8.1.1 2006-2007), in which several policy instruments and measures were identified to deal with invasive alien species as elaboration of the cross-sectorial Norwegian strategy. In addition, Norway participates in the European Environmental Agency (EEA) cooperation to report on biodiversity indicators (Streamlining European Biodiversity Indicators; SEBI), which is a Pan-European follow-up of the CBD indicators.

Currently the general framework in Norwegian law governing the introduction of IAS and the eradication of IAS is the Nature Management Act (Naturmangfoldsloven), which includes the protection of the natural environment, landscape and biological diversity. This new act came into force 1 July 2009. In addition, Norway was one of the first countries to ratify the International Convention for the Control and Management of Ships Ballast Water & Sediments (BWM) in 2010 and a national regulation on the handling of ballast water came into force later that year, significantly reducing the risk for the introduction of alien species overseas.

Per today, Norway has implemented five different action plans for the eradication of certain alien species (i.e. racoon dog - mårhund *Nyctereutes procyonoides*, Spanish slug - brunskogsnegl *Arion lusitanicus*, the fish parasite - gyro *Gyrodactylus salaris,* Eurasian minnow - ørekyt *Phoxinus phoxinus* in Namsen River and American mink – Amerikansk mink *Neovison vison*) (see Chapter 6).

Progress towards the 2010 Biodiversity Target for IAS as threat to biodiversity and improvement of the indicators of IAS for the 2020 targets
A pressure-state response model[1] (after DPSIR - Driver, Pressure, State, Impact, Response -, a causal framework for describing the interactions between society and the environment, see also McGeoch et al. 2010 and Figure 1.) was used for measuring progress towards the 2010 Biodiversity Targets. Within this model four indicators were developed and expressed for the purpose of assessing progress adequately for IAS. The four indicators are:

- the status of alien species invasion expressed as the number of documented IAS per country (Pressure);
- the Red List Index for impacts of invasive alien species showing the overall impact of IAS on the extinction risk of species globally (State);
- trends in international IAS policy showing the number of international agreements relevant to controlling IAS, how this has changed through time as well as the change in the number of countries party to these agreements (Response);
- trends in national invasive alien species policy showing the percentage of countries with national legislation relevant to IAS concerns and how this has changed through time as countries acknowledge the IAS problem and commit to responding to this threat (Response).

Since the COP 10 meeting of the CBD in 2010, the CBD Ad Hoc Technical Expert Group met to discuss further improvement of the indicators for the Strategic Plan for Biodiversity 2011-2020 (High Wycombe, UK, June 2011). In addition, there was an Expert Meeting on improving the SEBI work (Copenhagen, Denmark, September 2011) to discuss the pros and cons of the SEBI indicators for IAS in Europe, and how to concertize the indicators (i.e. the cumulative numbers of alien species in Europe; the list of worst IAS threatening biodiversity in Europe; Abundance and impacts of IAS in Europe; Awareness of IAS in Europe; Cost of IAS in Europe) (Rabitsch et al. 2012). Rabitsch et al. (2012) suggest including pathways of alien species into the indicator to enable prioritizing pathways, supporting the precautionary principle and for coming in line with the new EU 2020 targets. Furthermore, they suggest not to include the list of worst IAS per country for the time being, as this may be misleading, but instead to develop new indicators, preferably 1) The Red List Index of impacts of IAS (see also Genovesi et al. 2012), and 2) The combined Index of Invasion Trends (Butchart et al. 2010) (Rabitsch et al. 2012). The list of worst IAS per country may be misleading because countries use different classification systems. For example the wild boar – villsvin *Sus scrofa*, is classified as having ‘severe impact’ in Norway while it is seen as native species in Sweden.

[1] The DPSIR model is also used in the programme ‘State of the Environment Norway’ by the Norwegians Ministry of Environment aiming to provide the general public with the latest information on the state and development of the environment. The service presents environmental topics in a simple and easy-to-follow way and provides access to more detailed scientific presentations. See http://www.environment.no/

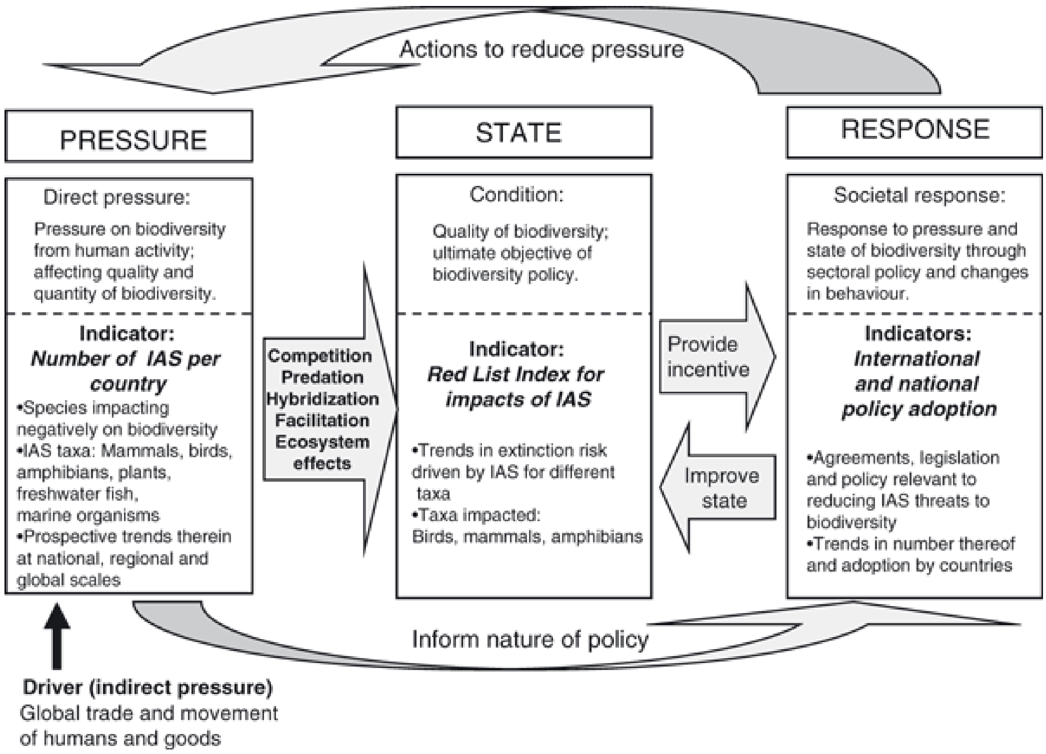


Figure 1. *Pressure-state-response model of the invasive alien species (IAS) indicators for reporting on the 2010 Biodiversity Target. Source: McGeoch et al. (2010).*

Relevant processes on indicator development in Norway

In the context of this pilot study, three processes in Norway are relevant:

- The indicators used in the 'Norwegian Environmental Status' (Miljøstatus i Norge, http://www.miljostatus.no/Toppmeny/Om-Miljostatus) to identify the status of the environment and how it develops. The aim of the 'Norwegian Environmental Status' is to establish a societal understanding of the status and developments of the environment, what is effecting it, what are the consequences of certain trends and what can be done against it. Indicators used in the 'Norwegian Environmental Status' with regard to IAS are given for 'sea and coast', 'mountains', 'rivers and lakes', 'cultural landscapes', 'forests' and 'wetlands', and include 'the number of eradication/reduction measures per species and per county' and 'the number of endorsed and implemented action plans'.

- In 2010 the Norwegian Nature Index (NI) (see Chapter 4 for detailed description) was established to provide an overview of the state and development of biodiversity in major ecosystems of Norway and thereby measure progress towards to goal of halting the loss of biodiversity.

- The launch of the Norwegian alien species database and the black list 2012 by NBIC (Gederaas et al. 2012; http://www.biodiversity.no/Article.aspx?m=173&amid=2578), which includes a systematic risk assessment per alien species. While the method is tailored to the Norwegian environment, it can easily be adapted to other countries, and fills a vital need internationally for quantifiable, uniform approach to classifying and assessing alien species. It provides an objective classification of these species' potential impact on the Norwegian environment. The method classifies species according to their reproductive ability, growth rate, individual densities, population densities, prevalence and their effect. This information allows the researchers to plot the risks posed by each species on two axes, one which shows the likelihood of the species' dispersal and ability to establish itself in the environment (along with its rate of establishment, if applicable) and the other shows the degree to which the alien species will affect native species and habitats. Based on the combined values of the two axes, the species can be placed in one of five risk categories: 1) Severe impact species that can have a strong negative effect on the Norwegian environment; 2) High impact species that have spread widely with some ecological impact, or those that have a major ecological effect but have only limited distribution; 3) Potential high impact species that have very limited dispersal ability, but a substantial ecological impact or vice versa; 4) Low impact species, with low or moderate dispersion and moderate to limited ecological effect; 5) Species with no known impact factor that are not known to have spread and have no known ecological effects (Gederaas et al. 2012, see also Figure 2.). The guideline for the method is currently only available in Norwegian, but is in the process of being translated into English.

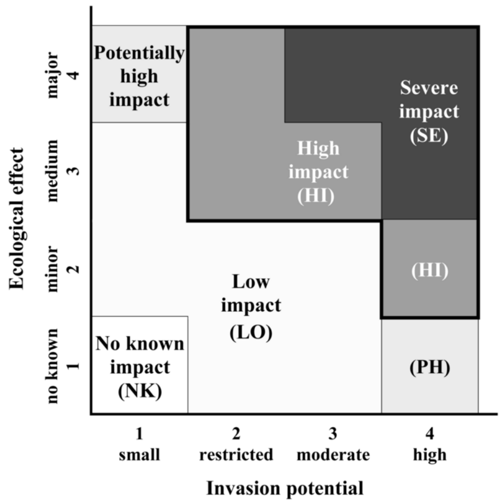


Figure 2. *Risk categories for alien species depending on their Invasion potential and ecological impact. The system operates with five risk categories (i.e. Severe impact (SE), High impact (HI), Potential high impact (PH), Low impact (LO) and No known impact (NK), depending on the interaction between invasion potential (Invasjonspotential) and ecological effects (Økologisk effekt). Source: Gederaas et al. (2012).*

Existing indexes relevant to this pilot study

Both during the CBD Ad Hoc Technical Expert Group meeting (Wycombe UK, June 2011) and during the Expert Meeting on improving the SEBI work (Copenhagen Denmark, September 2011) it was advised to work on standardized methods and to focus more on trend analyses (i.e. trends in the number and extent of IAS, in impact of IAS, in responses to IAS, in the impact of IAS on extinction risk trends of red list species, and trends in the economic impacts of selected IAS).

For measuring the progress towards the 2010 targets work had been done on monitoring and predicting the spread of IAS, controlling their pathways and vectors, quantifying their impacts and managing existing IAS by a vast number of organisations at all levels around the world (Kümpel & Baillie 2007). Nevertheless, McGeoch et al. (2006) recognized that by 2006, there was no fully developed indicator for IAS that combined trends, derived from a standard set of methods, across species groups, ecosystems, and regions. Therefore, according to Genovesi et al. (2012), the SEBI invasive species indicator (i.e. ‘the cumulative number of alien species in Europe since 1900’) as defined for the 2010 Biodiversity Target is the only regional indicator developed to date. The SEBI invasive species indicator is based on 163 species identified by a group of experts as causing severe impacts to biological diversity, to human health or to economy (EEA 2009).

For this pilot study the following approaches are relevant:

- The Red List Index of impacts of IAS (see also Genovesi et al. 2012)
- The Combined Index of Invasion Trends (see also Rabitsch et al. 2012)
- Index of Alien Impact (Magee et al. 2010)
- Living Planet Index (LPI) (Loh & Glodfinger 2006)
- The Index of Invasion Level (Catford et al. 2012)
- The Bio-pollution Index (Olenin et al. 2007; Zaiko et al. 2011)

The Red List Index of impacts of IAS (source McGeoch et al. 2010)
The Red List Index has been developed as an indicator of trends in the status of biodiversity. It is calculated from the number of species in each Red List category (Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct), and the number changing categories between assessments as a result of genuine improvement or decrease in status (category changes owing to improved knowledge or revised taxonomy are excluded). The original methodology was described in detail in Butchart et al. (2004, 2005), and revised in Butchart et al. (2007). A combined Red List Index of species survival for birds and mammals (and in preliminary form for amphibians and corals), showing the proportion of species expected to remain extant in the near future without additional conservation action, was published in Hilton-Taylor et al. (2009). The Red List Index falls under the ‘State’ part of the DPSIR model and it assesses the delisting (e.g. from Endangered to Vulnerable) or up-listing (e.g. from Endangered to Critically Endangered) of the different Red List species as a result of for instance alien species eradication programmes or increased alien invasiveness. It is difficult however to use this indicator of trends for smaller geographic units and for different ecosystems within one country.

The Combined Index of Invasion Trends (source Rabitsch et al. 2012)
Butchart et al. (2010) proposed a Combined Index of Invasion Trends, based on the DAISIE dataset (Delivering Alien Invasive Species Inventories for Europe see http://www.europe-aliens.org/default.do), that has been included in the Global Biodiversity Outlook 3 (Secretariat of the Convention on Biological Diversity, 2010). The index is based on the number and distribution of alien mammal, amphibian, bird, freshwater fish, vascular plant and marine species in a stratified-random selection of 57 European countries/regions representative of different climates, regions, country sizes and development status. The indicator was based on 542 alien species and 2871 species-country records. Based on this dataset, a European trend was calculated as the geometric mean of indices for the number of alien species of metazoans in the Mediterranean, freshwater animals, and mammals across all European countries (27 EU member states, plus Andorra, Iceland, Liechtenstein, Moldova, Monaco, Norway, Russia, Switzerland, Ukraine, and former Yugoslavian states). The Combined Index of Invasion Trends falls under the ‘Pressure’ part of the DPSIR model and allows comparison between large geographic regions/countries.

Index of Alien Impact (source Magee et al. 2010)
Magee et al. (2010) developed an Index of Alien Impact (IAI) to estimate the collective ecological impact of *in situ* alien species. IAI summarizes the frequency of occurrence and potential ecological impact (Invasiveness-Impact Score (Ii)) of individual alien species for all aliens present in a particular location or community type. A component metric, Ii, is based on ecological species traits (life history, ecological amplitude, and ability to alter ecosystem

processes) that reflect mechanisms, which can increase impact to ecosystem structure and function. The IAI also falls under the 'Pressure' part of the DPSIR model and is tested for streamside vegetation of a river basin in eastern Oregon, USA and addresses the potential utility of the IAI for prioritizing alien species management activities and informing restoration goals (Magee et al. 2010).

The Living Planet Index (LPI) (Loh et al. 2005; Loh & Goldfinger 2006)
The Living Planet Index (LPI) is an indicator of the state of global biological diversity ('State' part of the DPSIR model), based on trends in populations of species from around the world. The LPI provides the general public, scientists and policy-makers with information on trends in the abundance of the world's species and offers insights into which habitats or ecosystems have species that are declining most rapidly. According to Kümpel & Baillie (2007) trends in selected populations of IAS could be extracted from the Living Planet Index (i.e. the 'Pressure' part of the DPSIR model), once the database has been updated to include a field for alien/invasive status. If additional IAS populations are identified during the IAS data evaluation process, they could also be added to the LPI database. Trends could be measured in absolute terms or by recording an IAS as 'stable', 'increasing' or 'decreasing'. The Global Invasive Species Database (GISD) includes a field called 'occurrence type', which logs IAS as 'established and expanding', 'present and controlled' or 'eradicated', and could form an additional data source or data capture facility if linked to the LPI. If sufficient data were available, this could then be disaggregated to produce trends in IAS populations by region, biome or taxonomic group.

An index of invasion level (source Catford et al. 2012)
Catford et al. (2012) aimed to identify the best way to quantify the level of invasion by non-native animals and plants by reviewing the advantages and disadvantages of different metrics. This approach also falls under the 'Pressure' part of the DPSIR model. Based on their review work, two invasion indices were recommended, i.e. 'Relative alien species richness' and 'Relative alien species abundance' indicating the contribution that alien species make to a community. The relationship between relative alien richness and abundance can indicate the presence of dominant alien species and the trajectory of invasion over time, and can highlight ecosystems and sites that are heavily invaded or especially susceptible to invasion. Splitting species into functional groups and examining invasion patterns of transformer species may be particularly instructive for gauging effects of alien invasion on ecosystem structure and function. Establishing standard, transparent ways to define and quantify invasion level will facilitate meaningful comparisons among studies, ecosystem types and regions. It is essential for progress in ecology and will help guide ecosystem restoration and management.

The Bio-pollution Index (http://www.corpi.ku.lt/databases/index.php/binpas/) *(IMPACT)*
To develop potentially useful indicators, especially of impacts of invasive non-native species (such as the bio-pollution indexes) remains the main concern for achieving good environmental status (Olenin et al. 2007). The degradation gradient in relation to non-native species is a function of their relative abundances and distribution ranges while the magnitude of impacts may vary from low to massive and they can be sporadic, short-term or permanent (Olenin et al. 2007). To build a platform to uniform bio-pollution measurements units the <u>B</u>iological <u>In</u>vasion Impact / Bio<u>p</u>ollution <u>A</u>ssessment <u>S</u>ystem (BINPAS) was created. BINPAS is an online system (http://www.corpi.ku.lt/databases/index.php/binpas/) to translate the existing data on miscellaneous invasive alien species impacts into uniform bio-pollution measurements units. Bio-pollution is defined here as the impacts of invasive alien species at the level which disturbs ecological quality of aquatic and terrestrial ecosystems by effects on: an individual (internal biological pollution by parasites or pathogens), a population (by genetic change, i.e. hybridization), a community (by structural shift), a habitat (by modification of physical-chemical conditions), or an ecosystem (by alteration of en-

ergy and organic material flow). Development of the BINPAS was supported by the ‘Marine Ecosystem Evolution in a Changing Environment’ (MEECE) project and the ‘Biological invasions in Lithuanian ecosystems under the climate change: causes, impacts and projections’ (BINLIT) project. Between 2012 and 2014 they aim to merge BINPAS and the DAISIE database together. The BINPAS approach has been tested for several terrestrial and aquatic species, especially for the coastal and marine zone in Lithuania and for a Lithuanian inland lake.

In conclusion
As one can read from above, different indices use different approaches and serve different purposes. Certain indexes are useful for comparison of different geographic levels (Pan Europe, Europe, regional, national) and some use different biotic levels (at the species or taxonomic group level), while other indexes also include impact assessment on the ecosystem level. Although most of the indices focus either on the Pressure (drivers) or on the State part of the DPSIR model, none of them combines it with the Response part (i.e. number of eradication programmes, monitoring programmes, budget assigned to eradication etc.). In addition to measuring the rate of loss of biodiversity, it is as important to monitor the drivers of this loss, and actions in place to address the drivers/pressures. Thus, ultimately, by combining all three types of indicators (pressure, state and response), a measure of overall conservation effectiveness should be possible according to Kümpel & Baillie (2007).

However, the problem with these indexes is that the underlying IAS listing processes which form the building blocks of the indices are set up differently per country (see also discussion by McGeoch et al. (2012)), which not only hinders the overall comparison of the lists but also results in a substantial error when these lists are further used in these indices. The Norwegian Nature Index work (see below) has reduced subjectivisms in the assessment of ecosystems while at the same time accounting for the complexity of ecosystems applicable to the Norwegian situation; a framework, which is flexible enough to adapt to country specifics, but general enough to allow comparison between countries and larger regions. It is therefore very reasonable to explore if and to which extent the Norwegian Nature Index framework is applicable to use for building the IAS Index so that a range of taxa, different spatial scales, temporal trends in invasions and impacts of invasive species are considered.

3 The Norwegian Nature Index

We have been asked to evaluate the potential for applying the framework of the Norwegian Nature Index (NI) to Invasive Alien Species (IAS), thereby creating an index of value for society at large and management in particular. We begin with discussing some key properties of the NI and its potential as template for an IAS-index.

What is the Norwegian Nature Index?
The Nature Index (NI) is a quantification of the condition and trends of biodiversity in ecosystems and is based on a range of indicators representing biodiversity. The best available knowledge for each indicator is used in the NI. NI is calculated as a weighted average of the scaled indicators where the value 1 represents intact ecosystems and the value 0 represents damaged ecosystems. Per today 308 indicators are included representing main seven ecosystems (i.e. oceans, coastal waters, lakes, open plains, forests, marshes and wetlands and mountains). Indicators which are included are species representing different taxonomic and/or functional groups. The indicators are sensitive to different types of environmental changes, so that the overall effect of negative anthropogenic pressures on biodiversity should be read in the NI.

The indicators are scaled to a value between 1 and 0, where 1 denotes the value it has in its reference state and several mathematical models are used (see below, Certain et al. 2011). An index value of 1 reflects thus an ecosystem in a reference condition. Reference values for the indicators are determined by a reference state for the whole ecosystem. The single indicator reference value, however, is its species abundance in intact ecosystems with little impact from human activity such as protected forests and national parks in the mountains for instance. For cultural-historical landscapes an index value of 1 represents ‘good practice with traditional management’ relative to the specific biodiversity existing in these cultural-historical landscapes. Open lowland is the only ecosystem of the NI that uses this latter definition of the reference state. The advantage of having one definition of the reference state for all ecosystems is that NI of the different ecosystems are thus equally sensitive to any (negative) influence.

The NI database is structured around population numbers and geographic distribution for the various indicators (i.e. species or surrogates for species). The knowledge may be based on monitoring data, expert judgment or models. Here it is important to note that an expert review of a population size is a collection of the information one has from the best available sources (e.g. monitoring, research and/or field observations), and therefore it is only an expert judgement for a given area and/or period. For each population number one includes a level of uncertainty, i.e. how secure is the knowledge of this. These uncertainties are included in the statistical analysis when the overall Nature Index is calculated. As a unit for population size one can use presence – absence data, biomass, actual population numbers or population density.

For the NI the smallest geographical resolution is at the municipality level but data available at the level of Counties or larger regions can also be included. It is also possible to use other geographical entities, e.g. national parks, but then one has to have digitized boundaries for these.

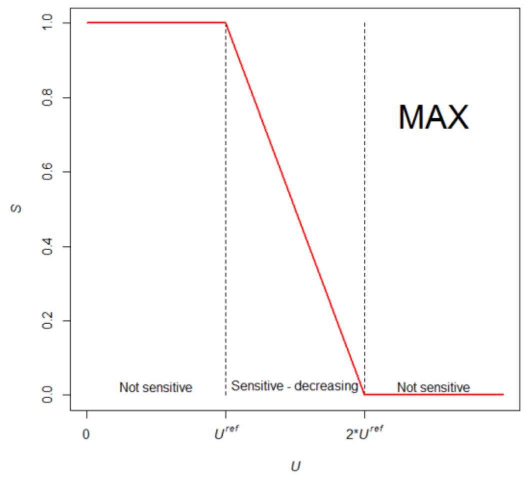
Mathematical background of the NI
The NI combines a multitude of indicators, each representing a separate aspect of biodiversity in Norway. The indicators are chosen by an expert group so that they together (as far as possible) give an exhaustive account of Norwegian nature. It is flexible in that it can

be calculated for an almost unlimited amount of subsets, both thematic (such as ecosystems) and geographical (such as counties and larger regions). The index is estimated with confidence intervals around its point estimate, both providing information about the level of knowledge and enabling statistical hypothesis testing. The index can thus answer questions such as “Has the quality of the forests in region Western Norway (Vestlandet) increased or decreased in the past five years?”

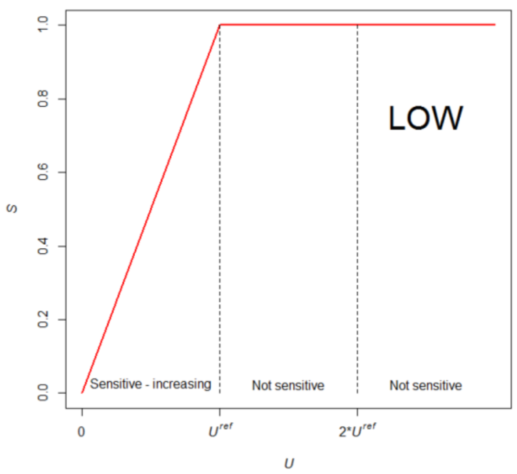
Technically, the index is constructed as a scaled weighted average. These three properties (i.e. scaling, weighting and averaging) are key elements of the NI, and we now discuss their consequences for a possible IAS index.

Scaling
Since the different indicators in the NI can span a wide range in values, they cannot be directly compared to one another (is for example 5 million cod better than 1 thousand hollow oaks?). Therefore, each indicator is scaled by a scaling function to create comparable values. The NI uses scaling functions that has a reference value (U^{ref}) as the only parameter, representing intact ecosystems or for traditionally managed ecosystems a historical reference state. This reference value is determined by expert elicitation. In all scaling functions, the indicator is in some way expressed as the difference between the observed state and the reference state. The indicators are bounded between 0 and 1, with a value of 0 indicating a completely impoverished state of biodiversity and 1 representing an optimal value.
The reference values have several functions in the NI. First, they communicate the reference states and deviations from these states in an understandable way, where for instance an indicator value of 0.7 means that there is currently 70 % of biodiversity, compared to a reference state. Secondly, it defines the range of observed values that can influence the index, by determining at what values the scaling functions reach 0 or 1. For example, using the MAX model, the sensitive area ranges from U^{ref} to $2*U^{ref}$, i.e. observed values above 2 times the reference state does not further affect the index (Figure 3.a). For the LOW model, the sensitive area ranges from 0 to U^{ref} (Figure 3.b), and for the OPT model[2] the sensitive area ranges from 0 to $2*U^{ref}$ (Figure 3.c). Thirdly, the reference value defines the slope of the scaling function, and thereby the sensitivity of the index. A higher reference value means that a larger change of the observed value is required to register a change in the scaled value, and therefore also in the index.

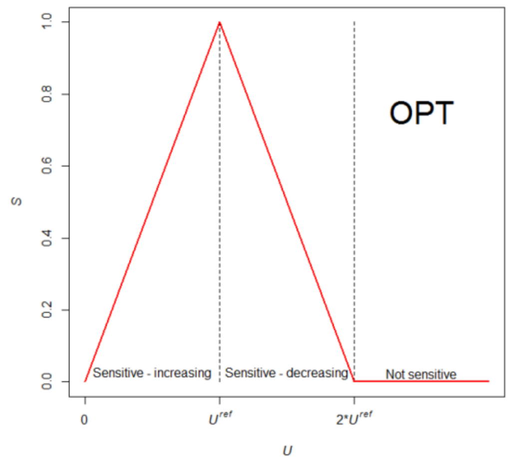
[2] The OPT model was included when the Nature Index was launched in 2010 but after evaluating the framework it has been decided to take out the OPT model in future work of the Nature Index.



a)



b)



c)

Figure 3. *Scaling functions in the Nature Index for Norway indicating the scaled value S as a function of the observed states U. U^{ref} indicates the optimal states, but also defines the slope and the sensitive ranges of the observed values.*

The scaling functions used in the NI are not directly transferable to an index of IAS. The OPT model is unimodal, meaning that there is a single maximum point with decreasing values surrounding it. This model is unsuitable for IAS since potential positive effects of IAS are by definition not considered. Increasing the level of IAS should never lead to more desirable states, which would be the case with the OPT model. The MAX scaling function also is problematic from an IAS perspective. Since IAS are completely unwanted, the reference state is by definition 0. However, this would lead to $2*U^{ref}$ not being defined, thereby rendering the MAX scaling function nonsensical. Alternatively, setting a reference value above zero would beg the questions why levels below U^{ref} or above $2 * U^{ref}$ does not affect the index. Thereby the LOW model is most promising, but it still needs to be modified and reinterpreted to work with IAS. We discuss such a modification below in chapter 5 which outlines the proposed index.

Weighting
Since the different indicators in the NI are not considered to be equally important for the different ecosystems that constitute the NI, the indicators are weighted. Species that are seen as especially representative of a particular ecosystem are given more weight than other species. However, ecosystems within an area weigh equally, as one ecosystem is not considered more important than another. In principle, a similar weighting regime is a reasonable approach also for an index of IAS, and would enable the index to be estimated for several different ecosystems and regions, a key quality of the NI. However, since IAS are not associated or typical to native ecosystems but rather the opposite, the weights would have to be modified and reinterpreted, modifications that we discuss also in chapter 5.

Averaging
The NI is defined as the average state of biodiversity, given the complete set of indicators, which are chosen to, as far as possible, represent all aspects of biodiversity in all ecosystems in a region or an entire country. If an ecosystem for example has two indicator values, one with a scaled value of 0.3 and the other of scaled value 0.7, the combined index for that region is 0.5 ((0.3+0.7)/2).

However, this is a counterintuitive way of aggregating an IAS-index. Why should an IAS-index represent the average spread or impact of IAS in an ecosystem, region or country? Intuitively, a colonisation by a new IAS should always worsen the index. With an averaged index, this is not necessarily the case. In fact, a colonisation of a new species that results in the inclusion of an additional indicator would probably lead to a better overall score, since novel colonisations are likely to have distributions, abundances, or impacts that are lower than the current average.

In some respect, this problem is also present in the NI. The selected set of indicators that constitute the NI could potentially be changed in the future (as it has been in the past), removing some indicators and adding others. This leads to a different estimated average state, even though the actual state has not necessarily changed. This artefact is dealt with in the NI by recalculating the index, based on the updated set of indicators. By doing this, earlier calculations of the index are rendered obsolete, and one must always refer to the latest version of the index when comparing present index values with past index values. This can be acceptable if the indicator set is not changed too often, and if the addition or subtraction of indicators in itself is not of particular interest, as is the case with the NI. There, an average state of each indicator is a reasonable formulation of the index.
However, for an IAS index it seems natural that it should capture the total impact of IAS rather than the average impact, or a total abundance of IAS rather than the average abundance. In addition, a natural task for an IAS-index is to monitor the colonisation (and in case of successful eradication, the elimination) of alien species. It seems illogical that a colonization of a new IAS, or a successful eradication of an IAS not necessarily would influence the estimate of the current state, while always affecting estimates of past states. As the new value of the index could only be interpreted in relation to the past values, and the past values would constantly change, an averaged IAS-index thus risks being an index that mainly rewrites history.

In summary, despite the various problems outlined above connected to a direct implementation of the Nature Index for Norway framework on IAS, there are still elements of the NI that is potentially suitable for IAS. The NI has several beneficial qualities that would be suitable also for IAS, but the methodology is not directly transferrable to IAS. The scaling functions, the weighting scheme, and the procedure for averaging need to be modified. In chapter 5 we present a sketch of a tentative implementation of the Nature Index framework for IAS.

4 An outline for an IAS Impact index inspired by the Norwegian Nature Index

Following the discussion outlined in chapter 4, it seems both practical and relevant to measure the number of present IAS and their abundance and distribution.
Using the NI as inspiration and general framework, we propose to construct an IAS index in the form of a scaled weighted sum, which can be summarized per ecosystem or geographical region, or both. An index value of zero would mean that there are no IAS present, with increasing values as IAS increases, either in their abundance, distribution or ecological impact.

Some key properties of the proposed index:

- The index is expressed as a scaled weighted sum, measuring the total presence or potential impact of IAS
- The lowest possible value, indicating the desired state is 0
- The index is open ended, with the highest possible value equal to the total number of IAS in an ecosystem or geographical region
- The index can be estimated for a specific ecosystem, geographical region or a set of ecosystems in a geographical region
- The index is presented as a point estimate with confidence intervals
- Useful both as a measure of state and trends (including rate of change)
- Index values increase with increased estimated potential for invasion
- Index values increase with increased number of IAS present
- Index values increase with increased abundance or spread of IAS
- Index values increase with increased estimated potential for ecological impact of IAS

Scaling

As in the NI, we use a scaling function to transform the observed raw values of indicators (species) to comparable scores. We take the LOW model from the NI as a starting point since this is the only scaling model within the NI that has monotonically increasing behaviour. Arguably, the desired state of an IAS is to be not present at all, i.e. having a distribution of 0. Therefore, an observed value of the alien species (U) of 0 should give a scaled value (S) of 0, 0 designating the desired state of zero impact. From there, increased abundance of IAS leads to increased indicator values until reaching 1, beyond which further increase of the IAS does not influence the indicator (see for illustration Figure 3). This behaviour of increasing values that reach a plateau is captured by the LOW scaling model.
Furthermore, we consider it to be a key quality of an IAS index to be sensitive to colonisations of new alien species, even if their initial distribution is limited. Therefore, the y-intercept of the scaling function should preferably not be 0. If the y-intercept is set to 0, a single observation of an alien species will not impact the index enough to be discernible. The y-intercept of each species scaling function can be thought of as the indicator value one wishes to attribute that species when it has the lowest detectable abundance, in a perfect case when it has just arrived to a region or country. We propose that the y-intercept of the scaling model should capture some measure of risk of invasion for each species in a particular ecosystem ($S_{ij}^{intr}\text{for species } i \text{ in ecosystem } j$). A limited colonisation of a species with poor potential for further spread does not need to influence the index as much as an invasive species with high potential for further spread. Recently, NBIC developed an ecological risk assessment of alien species in Norway (Gederaas et al. 2012). Their risk assessment is based on two axes: invasion potential and ecological impact. We propose to use the invasion risk axis developed by NBIC to inform the placing of the y-intercept of the scaling function. Their risk assessment scores are integer values on an ordinal scale rang-

ing from 0 to 4, with 4 representing “High chance for establishment or spread” and 0 representing “small chance for establishment or spread”. These values need to be converted to an interval scale before they can determine the placement of the y-intercept of the scaling model. Additionally, they need to be specified specifically to each species and ecosystem combination.

The second parameter of the scaling function is the reference value (U^{ref}), which defines were the function reaches a plateau at its highest score. This point determines several properties of the scaling function; what abundance or distribution of an IAS that will produce the highest score, the sensitive range of observations, and the slope and thereby the sensitivity of the index. This point is not as easily derived on logical grounds as the y-intercept. There are of course natural limits to the spread of a species, e.g. full coverage of potential land surfaces for a plant, or the infestation of an entire host population for a parasite. Since these levels are unlikely to be observed, however, they are not particularly relevant to the index and therefore to the scaling function. In addition, a very high U^{ref} value would make the index insensitive to the changes in abundances or distributions that we are likely to observe.

A possible definition of the reference value is the abundance or distribution where the IAS starts to dominate the community or where the IAS starts to have a negative effect on the natural biodiversity, expressed in some quality that is relevant for the species in question. This level could be identified by expert elicitation. Such a definition would conveniently set the slope of the scaling function to a suitable value. It would also naturally mark a range where it is reasonable that changes in the observed values affect the index. It is of limited use to let a further increase of an IAS to continue to affect the index if it already has a dominating position in a particular ecosystem. Still, what constitutes a “dominating influence” needs to be properly defined, a task that is beyond the scope of this report. Further, the reference value needs to be explicit for all combinations of species, ecosystems and regions (U_{ijk}^{ref}). Thus, it would be defined as the abundance or distribution at which species *i* “dominates” ecosystem *j* in region *k*.

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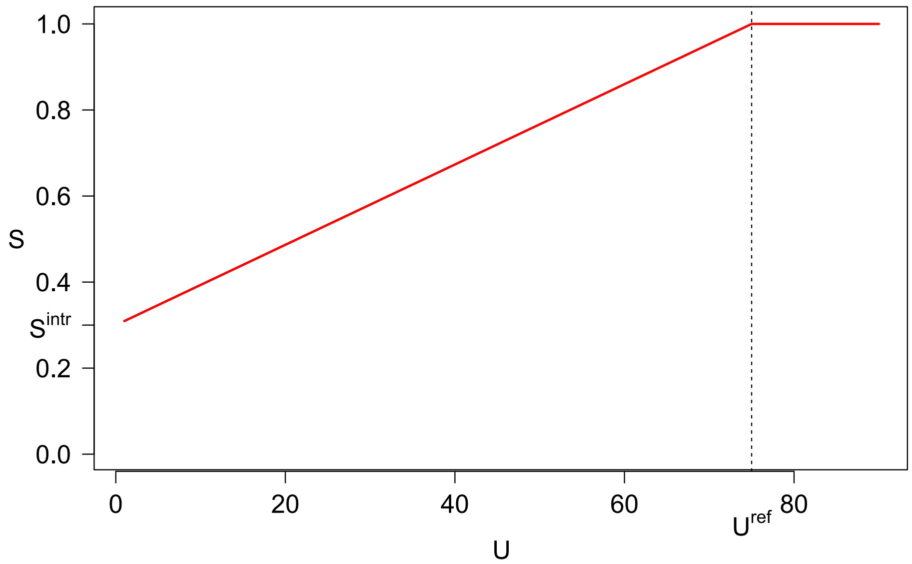

Figure 4. *Graphical representation of the scaling function of the proposed IAS index*

Weighting

In the Nature Index, species are evaluated as being more or less typical to or associated with a specific ecosystem. They are therefore given weights, ranging from 0 to 1 that represents the strength of these associations. These values determine how much each indicator will benefit the local state of biodiversity, and thus increase the index. A similar approach can be used in an IAS index, but here the indicators have a negative impact on the local state of biodiversity. The risk assessment of alien species developed by NBIC (Gederaas et al. 2012) contains an axis that signifies the ecological impact associated with each species. This is based on the documented or estimated likely potential for each IAS to have negative effects on native species or ecosystems, spread foreign alleles, pathogens or parasites (see also Chapter 2). We propose to use this axis as the basis for the weights in the IAS index. As with the scores on the invasion potential axis, this needs to be converted to a suitable interval scale. In addition, since our implementation discriminates between different ecosystems, the assessment of the ecological risk would need to be specified specifically for every IAS (*i*) in every ecosystem (*j*). Further, if the intention is to calculate the index for an ecosystem, further weights can be introduced to acknowledge the fact that different ecosystems have differing regional extent in any given region (k), creating weights W_{ijk}, in direct concordance with the NI. However, developing these weights is beyond the scope of this report.

Type of data

The proposed index need input data of four types;

1) constants that determines the y-intercepts of the scaling functions, (S_{ij}^{intr}), which signifies the invasion potential by an alien species i in ecosystem j (proposed to be based on NBIC risk assessment),

2) reference values, (U_{ijk}^{ref}), that defines the abundance or distribution where species i “dominates” ecosystem j in region k,

3) weights that correspond to the ecological impact of species i in ecosystem j in region k, (W_{ijk}), and

4) estimates of the current abundance or distribution of each invasive alien species i in ecosystem j in region k, (U_{ijk}), including statements of the associated uncertainty.

The reference values (U_{ijk}^{ref}) and the values of the current state (U_{ijk}) could either be expressed as number of individuals, or as areal distributions of an arbitrary unit. The important thing is that both values are expressed in corresponding units, which is practical for experts to use.

Mathematical definitions

We adopt the general framework of the nature index but introduce several modifications. The index (IAS) is defined as $IAS = \sum S_{ijk} * W_{ijk}$, where S_{ijk} and W_{ijk} can take values between 0 and 1, i.e. $S_{ijk}, W_{ijk} = \{0,1\}$. Since S_{ijk} and W_{ijk} are bounded by 0 and 1, the IAS index is bounded by 0 and the amount of IAS present in the ecosystem or region the index is estimated for, i.e. $IAS = \{0, Number\ of\ IAS\ present\ in\ nature\ type\ or\ region\}$.

The scaling function is defined as $S_{ijk} = S_{ij}^{intr} + \frac{(1-S_{ij}^{intr})}{U_{ijk}^{ref}} * U_{ijk}$, where S_{ij}^{intr} is the invasion potential of species i in ecosystem j (derived from NBIC ecological risk assessment), and U_{ijk}^{ref} is the abundance or distribution of species i where it “dominates” ecosystem j in region k, and U_{ijk} is the observed abundance or distribution of species i in ecosystem j in region k.

Like the NI, the index is not calculated analytically, but rather estimated empirically. Many U_{ijk}values are drawn from a statistical distribution that best fit the estimated observed values $\hat{U}_{ijk}$, and its associated lower and upper quartiles ($Q_1; \hat{U}_{ijk}$ and $Q_3; \hat{U}_{ijk}$, respectively). From these values, a set of values is calculated for the index according to the equations above. The index is defined as the mean of this set of random draws. In its current implementation, the NI is defined as the median of the set of index values, but this is proposed to be changed to the mean (see Pedersen & Skarpaas 2012). Confidence intervals of the index are defined as the 0.025 and 0.975-quantiles of the set of index values.

Data input

The intercepts of the scaling function (S_{ij}^{intr}) corresponds to the invasion potentials and the weights (W_{ijk}) corresponds to the ecological impacts. These are in effect constants that should preferably be determined using well defined criteria, and we suggest to use the criteria outlined in the risk assessment of alien species in Norway by Gederaas et al. (2012). This would make the index transparent and traceable, and rest on a proven foundation.

The reference values (U_{ijk}^{ref}), indicates the abundance or distribution where the species have a dominating influence on the ecosystems (i.e. areal presence), which would need to be determined by expert opinion. Preferably, explicit guides should be developed for assessing the reference values, contingent on what ecological role each IAS plays in the ecosystem. For example, the reference value for Sitka spruce *Picea sitchensis* in a boreal forest could be based on the abundance of the native Norway spruce *Picea abies*. However, in ecosystems where an IAS does not replace the role a native species, the reference values would have to be defined differently. For example, the Sitka spruce does not replace a native coniferous species in coastal heath ecosystems. Here the reference value could possibly be the abundance or distributions when the coastal heath ecosystem becomes completely forested by Sitka spruce. As another example, the reference value of an IAS plant, that covers lake water surfaces, could be the distribution at which it covers half of the lake, or perhaps the entire lake.

The guidelines for these reference values would need to be developed by an expert panel of ecologists, to find criteria that are suitable for a host of ecological roles and ecosystems. This would be a major task of a further development of this index. However, the task is similar to setting the reference values in the NI, and thus we regard this task as practically feasible.

The observed values of the IAS ($\hat{U}_{ijk}$) could be estimated by expert opinion, similarly as in the NI. Available databases (e.g. Artskart) could form an information base for determining the abundance or distribution of a particular species in a particular ecosystem and region. Since the existing mapping of IAS is generally only rudimentary, these estimates would initially contain severe uncertainties, expressed in the upper and lower quartiles. The confidence bounds on the resulting IAS index would reflect this uncertainty, and possibly spur further efforts to increase our knowledge of the abundance and spread of IAS in Norway. As the index can be estimated for different regions, the management in each region could directly compare the state of knowledge in their region to other regions, by comparing the widths of the confidence bounds of the index.

Data availability

Data availability has been checked for possible use in the practical example. Relevant for Norway is the North European and Baltic Network on Invasive Alien Species database (NOBANIS) (see http://www.nobanis.org/) , the DAISIE database (now currently ongoing as DAISIE+ database, see http://www.europe-aliens.org/default.do;jsessionid=BE35088FDC4EF4E5F2BDF81499F343B9) and the data available at NBIC (see http://databank.artsdatabanken.no/FremmedArt2012). In addition, different researchers still have old or additional data not yet compiled in the NBIC database. Some of this is available at the institutional level. NINA has for instance an overall database on alien plant species. In these later cases data exists mostly only on those species which were once covered in different projects or which are monitored due to a certain impact assessment in a certain local area for instance. These datasets are not the results of national monitoring programmes and do not reflect the true distribution (history) per se.

The policy of NBIC has been, in close collaboration with the Norwegian participant node in the Global Biodiversity Information Facility (GBIF Norway), to facilitate open access of biodiversity datasets. Data on both native and alien species distribution are built onto a comprehensive database. Researchers from different Norwegian institutes collaborating on the compilation of red list and/or black list are contributing to this open access structure.

Although several regional databases for Europe exist, such as NOBANIS and DAISIE, these are not always adequately updated. DAISIE for example has started as EU project funding by the sixth framework programme of the European Commission and continues today as EU initiative (DAISIE+). Norway doesn't report to DAISIE+. Norway (the Directorate for Nature management) however, reports to NOBANIS, a European network on IAS established as a network between authorities of the region.

For the moment the NBIC database seems more adequately (see illustration below) updated and reliable also for in the near future. Although there is still a lot of data at the individual research level, the NBIC database on alien species gives a good start for collecting data needed for the calculations of the IAS Index. For ongoing and future monitoring programmes it would be recommended that contracts and/or description of works includes explicitly the obligation to upload the monitoring data to NBIC as an ongoing process in the monitoring work.

Because of the different assumptions (i.e. which species to include and which reference value to use per species) which need expert validation, the practical example uses arbitrarily chosen numbers for a selected number of species. This was also done to simplify the test case as to see if the mathematical framework works rather than that it directly reflects a real life trend analyses which on its turn could potentially lead to unnecessary confusion.

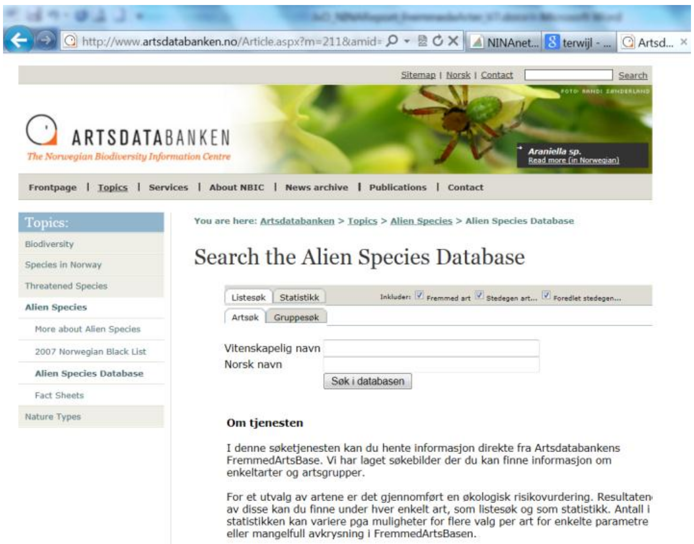

Illustration of the NBIC database on alien species

5 Practical example

Here we provide a hypothetical example to visualize the process of calculating the index practically. We stress that we use made up values and only a small subset of all alien species, ecosystems and geographical regions present in Norway. Ultimately, a complete implementation would require including all known alien species present in Norway, all major ecosystems and geographical regions. For this rudimentary example, we include the plant species; sycamore maple - platanlønn *Acer pseudoplatanus*, large-leaved lupin - hagelupin *Lupinus polyphyllus*, douglas fir - douglasgran *Pseudotsuga menziesii*, the mammals; muscrat - bisam *Ondatra zibethicus*, and wild boar and the insects; scarlet lily beetle - liljebille *Lilioceris lilii*, and golden spider beetle - messingtyvbille *Niptus hololeucus*.

Data

To calculate the index, a number of values need to be gathered. Firstly, the S_{ij}^{intr} values need to be specified, which determine the intercepts of the scaling functions and thereby the scaled values of the IAS when they have minimal abundance or distribution yet still are present. As explained above, these values will be based on the risk assessment of alien species in Norway published by NBIC (Gederaas et al. 2012). However, as the index requires that we provide values for S_{ij}^{intr} that is specific for each species and ecosystem combination, we need to specify invasion potentials at a higher resolution than what is available in the risk assessment published by NBIC. Similarly, the W_{ij} values symbolizing the ecological risk for each species in each ecosystem, need to be specified beyond the resolution that is currently present in the risk assessment of alien species in Norway published by NBIC.

Secondly, we need to establish a U_{ijk}^{ref}value for every species in every nature type in every geographical region. This represents the abundance or spread that is required for species i to dominate ecosystem j in region k. This can be specified either in terms of number of individuals, or as fractions of a distribution.

Lastly, we need estimates of the current abundance or spread for species i in ecosystem j in region k, $\hat{U}_{ijk}$, complete with estimates of its uncertainty expressed as the lower and upper quartile $Q1; \hat{U}_{ijk}$ and $Q3; \hat{U}_{ijk}$, respectively. This can be provided either as number of individuals of fractions of distributions. For example, if $U_{ijk}^{ref}$for Norway spruce is set to 10 million in the boreal forests of County “A”, meaning that 10 million spruce tree individuals are needed to dominate this ecosystem in this region, we can provide the $\hat{U}_{ijk}$ as for example 5 million trees. Alternatively, we could set U_{ijk}^{ref} at 1, designating “a dominating land cover”, and $\hat{U}_{ijk}$as 0.5. These two approaches would yield the same result.

For the purpose of this example calculation, we have set the values in Table 1 and Table 2 arbitrarily, to visualize some key properties of the index. Confidence intervals are based on 999 Monte-Carlo samples. For simplicity, only normal distributions are used to fit the distributions for U_{ijk}.

Table 1. *Values used in the example calculation of the IAS index.*

County	Species	Ecosystem	Invasion potential S_{ij}^{intr}	Ecological impact W_{ij}	Reference value U_{ijk}^{ref}	Observed value $\hat{U}_{ijk}$	Lower quartile $Q_1; \hat{U}_{ijk}$	Upper quartile tile$Q_3; \hat{U}_{ijk}$
A		Boreal forest	0.4	0.6	1.00E+10	1.00E+07	5.00E+06	2.00E+07
"	sycamore maple	River beds	0.1	0.9	5.00E+06	500 000	30 000	1.00E+06
"		Open lowland	0.4	0.6	5.00E+09	60 000	30 000	100 000
"		Boreal forest	0.1	0.6	5.00E+08	4 000	1 000	10 000
"	large-leaved lupin	River beds	0.4	0.9	8.00E+06	1.00E+06	500 000	6.00E+06
"		Open lowland	0.4	0.3	7.00E+09	100 000	50 000	5.00E+06
"		Boreal forest	0.3	0.6	1.00E+10	3.00E+06	2.00E+06	7.00E+06
"	douglas fir	River beds	0.1	0.9	5.00E+06	50	10	100
"		Open lowland	0.1	0.9	5.00E+09	200 000	70 000	450 000
"		Boreal forest	0.1	0.2	1500 000	50	10	500
"	muscrat	River beds	0.4	0.6	7 500	100	10	1 000
"		Open lowland	0.1	0.2	750 000	20	5	100
"		Boreal forest	0.4	0.6	10 000	0	0	0
"	wild boar	River beds	0.4	0.6	500	0	0	0
"		Open lowland	0.4	0.6	10 000	0	0	0
"		Boreal forest	0.4	0.2	500 000	5 000	2 000	50 000
"	scarlet lily beetle	River beds	0.4	0.2	100 000	10 000	500	50 000
"		Open lowland	0.4	0.2	500 000	20 000	10 000	700 000
"		Boreal forest	0.1	0.2	2.00E+06	10 000	2 000	500 000
"	golden spider beetle	River beds	0.1	0.2	50 000	0	0	0
"		Open lowland	0.3	0.2	1.00E+07	50 000	5 000	1.00E+06
B		Boreal forest	0.4	0.6	1.00E+10	1.00E+07	7.50E+06	1.25E+07
"	sycamore maple	River beds	0.1	0.9	5.00E+06	500 000	300 000	800 000
"		Open lowland	0.4	0.6	5.00E+09	60 000	30 000	100 000
"		Boreal forest	0.1	0.6	5.00E+08	4 000	1 000	10 000
"	large-leaved lupin	River beds	0.4	0.9	8.00E+06	1.00E+06	800 000	1.50E+06
"		Open lowland	0.4	0.3	7.00E+09	100 000	50 000	5.00E+06
"		Boreal forest	0.3	0.6	1.00E+10	3.00E+06	2.50E+06	5.00E+06
"	douglas fir	River beds	0.1	0.9	5.00E+06	50	30	80
"		Open lowland	0.1	0.9	5.00E+09	200 000	150 000	300 000
"		Boreal forest	0.1	0.2	1500 000	50	10	100
"	muscrat	River beds	0.4	0.6	7 500	100	70	200
"		Open lowland	0.1	0.2	750 000	20	5	100
"		Boreal forest	0.4	0.6	10 000	5 000	4 000	8 000
"	wild boar	River beds	0.4	0.6	500	100	50	200
"		Open lowland	0.4	0.6	10 000	6 000	5 000	8 000
"		Boreal forest	0.4	0.2	500 000	5 000	2 500	20 000
"	scarlet lily beetle	River beds	0.4	0.2	100 000	10 000	8 000	20 000
"		Open lowland	0.4	0.2	500 000	20 000	15 000	40 000
"		Boreal forest	0.1	0.2	2.00E+06	10 000	2 000	500 000
"	golden spider beetle	River beds	0.1	0.2	50 000	0	0	0
"		Open lowland	0.3	0.2	1.00E+07	50 000	10 000	100 000

Table 2. *Sizes in km^2 for each ecosystem for the two counties in the example calculation.*

Ecosystem	County A	County B
Boreal forest	10 000	30 000
River beds	2 000	6 000
Open lowland	8000	24 000

Results

Table 3 summarizes the results of the various subsets the index can be estimated for while Figure 4 illustrates these results for the purpose of clarification. For the entire region (County A and B together), the IAS index is 1.10 ('All' in Table 3.), reflecting the generally low abundances of the IAS in relation to the reference values. County A's index is lower than County B's, reflecting the fact that County B has one more IAS present (wild boar). Notice that the overall index (1.10) is not the arithmetic mean of County A (0.85) and B (1.18), but the weighted mean of the two counties, reflecting the different areas of the regions. This means that larger areas influence the index more than smaller areas. However, the overall index (1.10) is the arithmetic mean of the different ecosystem indices (1.34, 0.96, 0.99), reflecting the fact that the different ecosystems are considered to be equally important.

Because we used fictive values in Table 1 and Table 2 for simplification of the test case the results in Table 3 are not suitable to illustrate geographically. However, in reality and when the IAS Impact index is worked out with real data the IAS Impact index can also be illustrated using geographic maps as it is done for the Norwegian Nature Index.

Table 3. *Parameter estimates of IAS index in example calculation.*

Subset	Estimate (Mean)	Lower 2.5% - Upper 97,5%
All	1.10	1.00 - 1.19
County A	0.85	0.72 - 1.03
County B	1.18	1.08 - 1.29
River beds	1.34	1.18 - 1.54
Boreal forest	0.96	0.80 - 1.12
Open lowland	0.99	0.86 -1.12
River beds, County A	1.24	0.89 - 1.79
Boreal forest, County A	0.63	0.60 - 0.69
Open lowland, County A	0.71	0.61 - 0.92
River beds, County B	1.38	1.20 - 1.60
Boreal forest, County B	1.07	0.86 - 1.28
Open lowland, County B	1.09	0.94 - 1.25

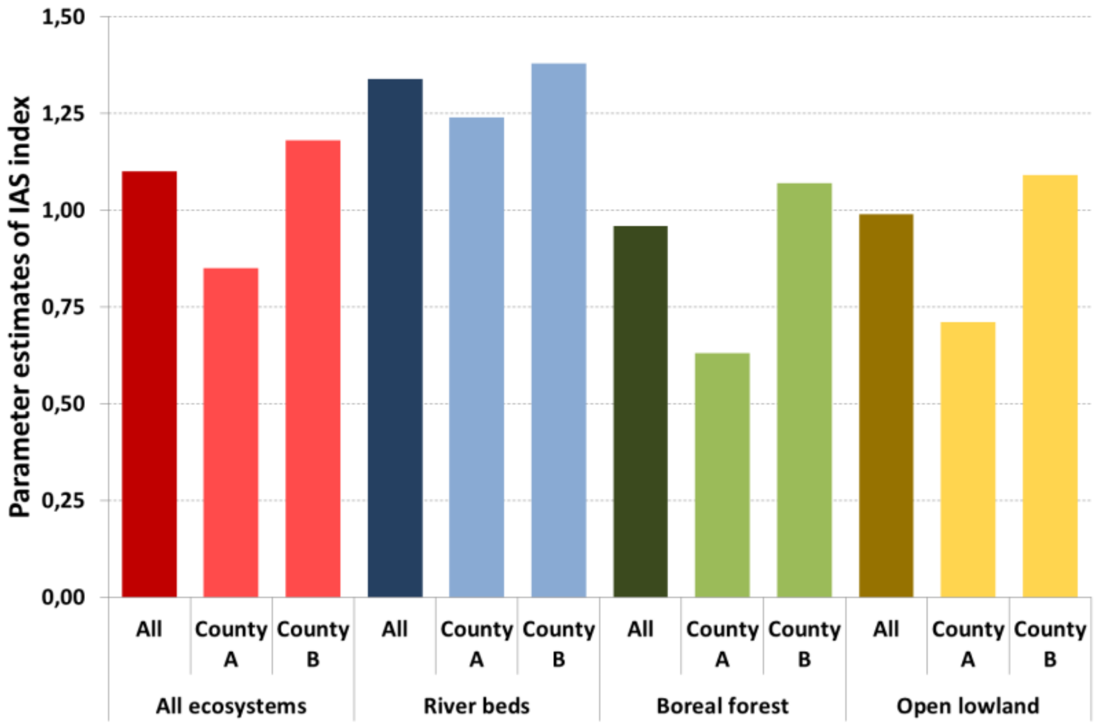

Figure 4. *Illustration of the parameter estimates of the IAS index for the various ecosystems*

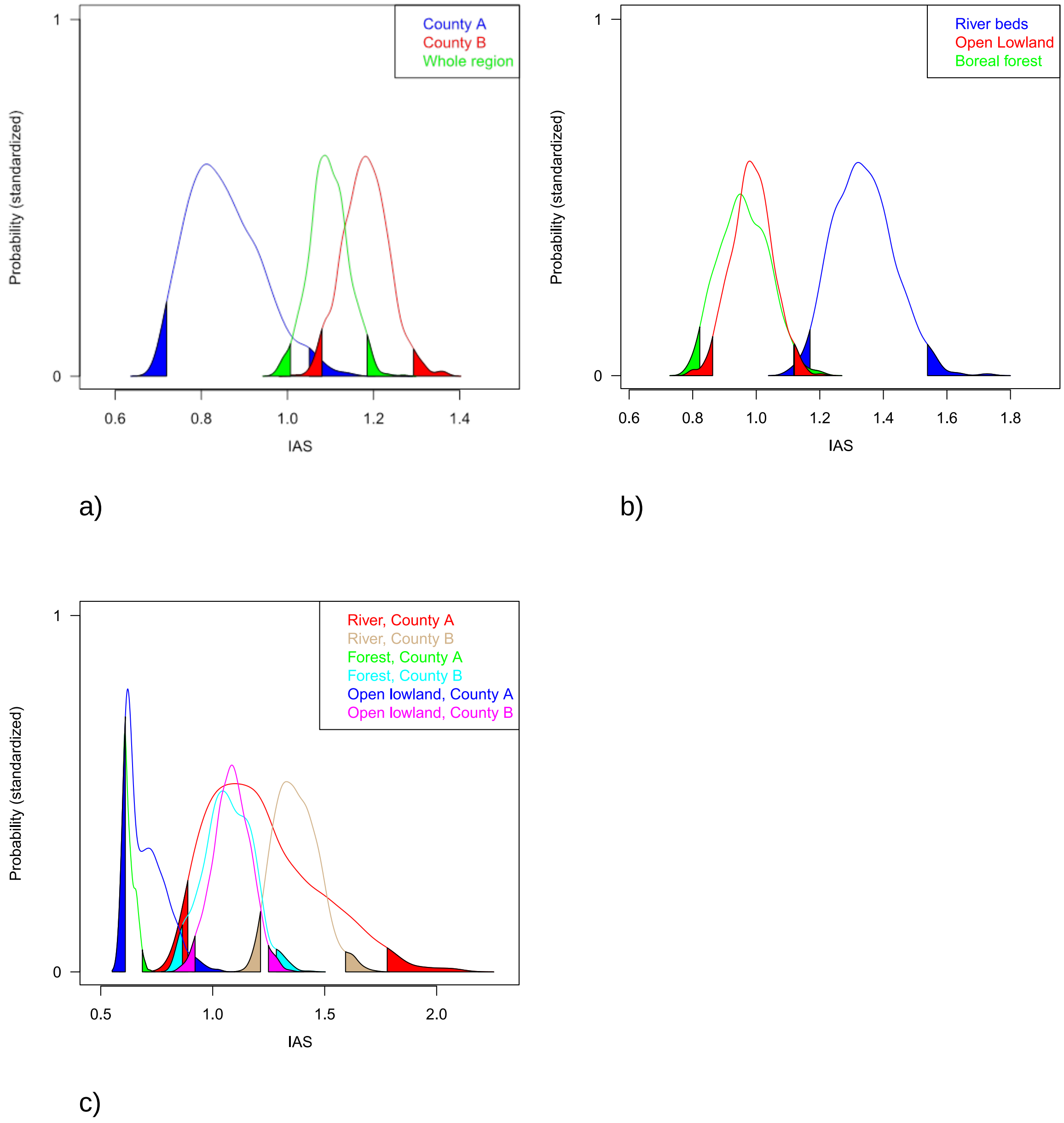

Figure 5. *Statistical distributions of the IAS index divided into a) geographical regions, b) ecosystems and c) geographical regions and ecosystems. Filled areas represent the lower 2.5% and the upper 97.5% confidence levels, i.e. the unfilled areas signify the 95% confidence intervals of each respective index. The y-axis is a measurement of probability, and has been standardized to simplify the graph.*

Figure 5a) shows the statistical distributions of the regional indices. We can see that the global index is more influenced by County B than County A, in accordance with its greater size. The abundances were also estimated with greater accuracy in County B than in County A (Table 2), which is visible in the wider confidence bands of County A.

Figure 5b) shows the statistical distributions of the index, divided into the different ecosystems. The higher values of “River beds” reflect the generally high weights of species in River beds, symbolizing the sensitivity of this ecosystem, as well as the rather high abundances in relation to the reference values in this ecosystem.

Figure 5c) shows the statistical distribution of the index, divided into ecosystems and regions. The Forest and Open lowland ecosystems in County A have the lowest values, reflecting the fact that the observed values in general are small compared to the reference values. These distributions are also considerably left truncated, reflecting the fact that the scaled values for the species that are present cannot be smaller than the value of their intercepts S_{ij}^{intr}, symbolizing their potential for invasion. In County B, an additional alien species is present (wild boar), thereby increasing these index values. The index distribution for County B is also considerably narrower than those for County A (except for the left truncation discussed above). This is due to the more precise estimations of the abundances in County B than in County A, which could be the result of monitoring programs being implemented in County B which increases the knowledge of the abundances and distributions of IAS.

6 Societal relevance and a management oriented Invasive Alien Species Index

In the example above (Chapter 3 – 6) we have deliberately not included an extra weighting representing total costs of eradication programmes as this will complicate the understanding of what the index represents. As Kümpel & Baillie (2007) stated: "the cost of control depends mainly on politics and national budgets, rather than the actual threats and potential impacts of IAS on natural biodiversity. It also varies as a consequence of differences in local economies (e.g. the costs of labour, equipment and implementation: Born et al., 2005). For those nations for which natural resources make up a considerable proportion of its Gross domestic product (GDP), the potential impacts and therefore resources expended on controlling IAS will be greater".

Kümpel & Baillie (2007) suggest that cross country analyses make no sense: It could however make sense within a country or a region. However, including management costs as an extra variable besides species distribution and proportion areal/ecosystem cover as surrogate for abundance (or abundance if available) as done in the above example doesn't enable clear communication of the interpretation of the trends for Invasive Alien Species in for example Norwegian terrestrial, limnetic or marine environment.

To show the decrease in number of IAS species, distribution and abundance in response to control of pathways or management actions it is possible to build an additional index next to the IAS index given in Chapter 3 – 6 using number of implemented action plans and a standardized form of all cost included (labour and equipment costs, collected from State, County and Municipality contributions and achievements, i.e. from the Mountain inspectorate (Fjelloppsyn), Norwegian Nature Inspectorate (SNO), State Road Administration (Statens veivesen) and Railway infrastructure (Jernbaneverket) and other relevant actors. However, this approach will only visualise the trend in IAS versus the total costs of control. Cost to society includes not only cost of control of IAS but also includes loss of resources as well as costs of lost biodiversity (which is inherently difficult to measure) (Mace & Taylor 2007).

Species specific management plans for the racoon dog, the Spanish slug and for the fish parasite were ready in 2008 as well as a special action plan for the eradication of the Eurasian minnow in the watercourse of Namsen exists and is being implemented. The management plan for the American mink has just been implemented (http://www.dirnat.no/content/2633/Amerikansk-mink-).

In addition to the species specific action plans, the action plan for the protection of coastal heather moorland (kystlyngheilandskap) includes the eradication of the sitka spruce - sitkagran *Picea sitchensis.* In 2010 the Norwegian State Inspectorate has started with the eradication of the Japanese rose - rynkerose *Rosa rugosa* and the sitka spruce in protected areas which is now extended with the eradication of the sycamore maple, Norway spruce - gran *Picea abies*, mountain pine - bergfuru *Pinus mugo uncinata*, mugo pine - buskfuru *Pinus mugo mugo,* Himalayan balsam - kjempespringfrø *Impatiens glandulifera and* other exotic garden plants.

According to the 2012 Norwegians state budget proposal (Prop. 1 S, (2011–2012)), several counties will be ready in 2012 with their county action plans against 'alien harmful species' which includes the prioritisation for management in protected areas and in municipalities. Also the national monitoring programme for biodiversity has been extended for several monitoring programmes especially for alien species. Table 4 gives the overview of the national monitoring programmes for alien species.

Table 4. *National monitoring programs for alien species per 2012.*

Pilot monitoring programs*

Type	Start	Responsible
1. Pathway – plant import	2011	NINA
2. Pathway – timber import	2011	NINA

*projects that will recommend the set-up and method of monitoring programs

Mapping programs

Type	Start	Responsible
1. Rapid Coastal Survey - County Hordaland	2010	HI (Marine Institute)
2. Rapid Coastal Survey - County Rogaland	2011	HI
3. Rapid Coastal Survey - County Østfold og Vestfold	2012	HI

Monitoring of aliens

Type	Start	Responsible
1. Monitoring of invasive fish	2011	NINA

Private persons and state employees are allowed to hunt American mink, raccoon dog, muskrat and wild boar all year round. For Canada goose – Kanadagås *Branta canadensis*, bar-headed goose – stripegås *Anser indicus* and muscovy duck – knoppand/moskusand *Cairina mochata* the hunting season is restricted to three to four months (August/September – December).

Because species specific eradication programmes are currently being implemented and especially those for alien mammals have just been started, no systematic data on labour costs and equipment costs are yet available. With regard to alien mammals (i.e. wild boar, muskrat, raccoon dog) budgets are currently worked out. For the eradication programme on mink the first systematic data collection on budget, effort and effect is undertaken. However, most of the eradication work carried out so far has not systematically been documented and often falls under daily tasks rather than it has its own predefined number of allowed labour hours and equipment costs (Kjartan Knutsen pers comm.). Although this might be different for the eradication programmes for alien plant and tree species, the problem here is that also other actors like the State Road Administration and Railway infrastructure have their eradication programmes. However, although the Norwegian cross-sectorial strategy on invasive alien species (2007) states that the Directorate for Nature management is responsible for the coordination of the different actions across the different sectors involved, also at the level of collecting data on input and costs with regard to the different eradication programmes, this has not been systematically set up per today.

Eradication can also be carried out by private persons, especially with regard to hunting alien mammals and birds. Animals taken out by private persons are not always reported. When one interpret any trend analysis for an area where public hunting is allowed, one needs to include an uncertainty in the interpretation of the observed trend when combining it with management costs. A possible reduction in number, distribution and/or abundance can in areas where local hunters are extremely happy to eradicate the mink for example be a significant factor for the cause of decline rather than the implementation of a management plan. Of course this may be different for cases when eradication programmes are targeted at relatively remote islands where the spatial overlap with private hunters should not exist. In these cases reduction in the target alien species should therefore be relative precise. Trends on mainland or larger islands would, however, be more difficult.

7 Discussion & recommendations

Assessing progress towards the 2020 Biodiversity targets with regard to IAS is complex and there are several possible indices of IAS, which each targets different aspects of this complexity. An IAS index could potentially measure for instance the state of native biodiversity degradation as a result of IAS. The state of native biodiversity is the focus of the Norwegian NI, which can be presented both in geographical or thematic subsets, e.g. of the state of forests in region Østfold. This index could however with relatively small effort possibly be adapted in the future to include a new thematic subset, i.e. the thematic subset 'species that is especially affected by IAS' for instance. The NI could then effectively capture the effect of IAS on native biodiversity. This new subset would require deliberation on which species are affected by IAS and which species are not. In addition it doesn't allow for further assessments on the level of IAS such as 'by which IAS is native biodiversity affected and what is the distribution and abundance of different IAS. It is also possible that the effect of IAS on native biodiversity doesn't show up as the factor responsible, for instance, for an overall decline in NI for a particular ecosystem or region. Often land use change or other factors may intervene and are maybe stronger drivers at the same time.

However, working towards an IAS Index and including invasiveness as starting point can cause discussion and disagreement in what invasiveness actually is. Using the basic principles from the Nature Index, we also included the term reference state. The reference state is defined as the abundance or distribution where the IAS starts to dominate the native biodiversity or where the IAS starts to have a negative effect on the native biodiversity, at a level identified by expert elicitation. This may make the exercise subjective especially there where there is insufficient data. In many cases, especially with marine species and invertebrates, we have no idea if an introduced species causes some kind of impact. This creates a bias that may cause problems when international comparisons have to be made and different experts groups for each country are defining IAS as being 'dominant' and 'having a negative effect on' differently from each other. The advantage is that we can build further on the standardized method presented by Gederaas et al. (2012) together with the experience with the Nature Index which showed that defining the reference state is an issue for experts to discuss and agree upon.

For international comparison a different type of index could be more feasible in which for instance the number of alien species as a proxy of Invasive Alien Species is given. The number of alien species is easier to standardized and will allow a credible comparison with other countries and as well as for different time periods within countries (Piero Genovesi, pers comm.). For Norway, it would be possible to compare the number of species on the alien species list published by NBIC with the number of species on the Red List species also published by NBIC. However, this comparison assumes equal impact of each alien species on biodiversity, which is a significant simplification of the real world. Of course, this also doesn't allow for any IAS impact assessment on different ecosystems. On the other hand, because of its simplicity, it is easy to communicate to the wider community and less sensitive to misinterpretation.

We have shown in the example case (Chapter 5) that the general principle of the Nature Index is applicable also to IAS, and that its algorithms can be adopted to calculate an index for IAS. The result is an index that is relatively easy to communicate and understand, can be subset very flexibly, and has confidence limits that would enable us to make statistical comparisons between different subsets and track trends. The proposed IAS index relies heavily on the work by the NBIC. We consider it beneficial to capitalize on the previous thorough work made by NBIC and their expert panels.

The close similarities with the NI and the proposed IAS index enables NINA to use the databases already constructed for managing the data for the NI, with some minor adaptations. This would lead to considerable reductions in cost in for a potential further development. In addition, a similar network of experts, partly overlapping with that of the NI, could be used to gather expert opinions on the current state of IAS in Norway.

The currently newly designed Nature Index database is being made more user friendly so that it is easier to enter data, images and reports. It will also enable the calculations of NI for different regions and different ecosystems more easily while background data is available online for viewing. In our opinion the NI database is suitable for IAS Index as outlined in this report. Minor adjustments have to be made, i.e. selecting which alien species or surrogates for these should be included, inclusion of a new field in the database to indicate intersection with the y-axis, and setting the year for which the index should be calculated. Furthermore, the automatic calculations need to be adjusted so that the estimations are in accordance with the new underlying formulas. The extent of these adjustments is likely to be small providing that the online graphical representations (maps and graphs) follow the same approaches as for NI. It is recommended to use a copy of the NI database as a starting point for the proposed IAS Index. The new NI database is ready to include the different datasets and the automatic calculations will be ready winter 2012-2013. A copy of the new NI database is free of charge but modifications of the database to be applicable for the IAS Index needs additional finances.

It will be possible to estimate abundance for some species for which abundance data is lacking, for example by developing methods for presence data (i.e. areal presence; see Skarpaas 2012). However, as we have seen in the practical example (Chapter 5) the IAS index is more trustworthy when the index distribution is narrower due to more precise estimations of the abundances for instance. Increasing monitoring efforts would certainly affect the IAS index in a positive way and the more data exists the better the IAS index reflects the actual status of IAS. Apart from this, there will always be a need for experts to ensure the quality of these abundance estimates. Further methodological developments also need to be made in order to make the index functional for a real world application. Specifically, definitions and numerical values of the scaling function's intercepts, the weights, and the reference values need to be discussed and tested. Especially also because our example includes the assumption that when IAS reach abundance (or areal presence) 0, the index will decrease showing an improvement (i.e. the state of IAS is better than when species X was still there). However, there are several introduced plant species for example which are seen as 'valuable' in Norwegian biodiversity. As Kümpel & Baillie (2007) stated: "IAS indicator development will necessarily be a work-in-progress; just as generally accepted and widely applied indices such as the Red List Index showed initial limitations and weaknesses that have now been overcome (Butchart *et al.*, 2004), so must any preliminary indicator for IAS be improved upon and developed further."

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876

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