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Unshifting the baseline: a framework for documenting historical population changes and assessing long-term anthropogenic impacts

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Keywords: ecological baselines, EPOCH assessments, anthropogenic impacts, population depletion, population recovery, shifting baseline

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Summary

Ecological baselines – reference states of species' distributions and abundances – are key to the scientific arguments underpinning many conservation and management interventions, as well as to the public support to such interventions. Yet societal as well as scientific perceptions of these baselines are often based on ecosystems that have been deeply transformed by human actions. Despite increased awareness about the pervasiveness and implications of this shifting baseline syndrome, ongoing global assessments of the state of biodiversity do not take into account the long-term, cumulative, anthropogenic impacts on biodiversity. Here, we propose a new framework for documenting such impacts, by classifying populations according to the extent to which they deviate from a baseline in the absence of human actions. We apply this framework to the bowhead whale

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(*Balaena mysticetus*) to illustrate how it can be used to assess populations with different geographies and timeline of known or suspected impacts. Through other examples, we discuss how the framework can be applied to populations for which there is a wide diversity of existing knowledge, by making the best use of the available ecological, historical, and archaeological data. Combined across multiple populations, this framework provides a standard for assessing cumulative anthropogenic impacts on biodiversity.

Introduction

The human footprint is now ubiquitous across the world's ecosystems [1,2]. Nonetheless the extent to which humans have already transformed the natural world is still poorly understood, and generally underestimated, because impacts started millennia ago (e.g., [27]), long before conventional ecological recordings started [3]. Furthermore, and even for relatively recent and ongoing changes, impacts tend to be progressively forgotten as human perceptions readjust, thus shifting the accepted norm for the condition of ecosystems [4–11]. This readjustment, what Pauly termed the "shifting baseline syndrome" [6] and Kahn Jr. called "environmental generational amnesia" [7], can be so rapid that even large and culturally significant species can be forgotten soon after they disappear [8], and it can take place even within individuals' lifetimes [4].

Returning to a planet with pre-human levels of disturbance is out of the question, but understanding how we have already changed and are continuing to change the world around us has important implications to our future capacity to inhabit it alongside other species. Firstly, it improves our knowledge of how ecosystems are structured, function, and evolve when not strongly moulded by anthropogenic pressures (e.g., [12]). Secondly, and by extension, it allows us to understand better the world we currently live in, how it has been shaped by the interplay between natural and anthropogenic processes (e.g., [13]), and how it will respond to future pressures. And finally, it broadens our ambitions regarding what is possible as future goals for the sustainable exploitation [14], conservation [15], and recovery of species [16] and ecosystems [17].

Here, we focus on understanding the past, cumulative human impacts on species' distributions and abundances. This is a first step towards a broader comprehension of ecosystem structure and function, and one with practical implications to conservation and management decisions. Indeed, decisions on which populations to exploit, to protect, to reinforce, to cull, to create or to extirpate are frequently underpinned by societal as well as scientific perceptions of whether the species is part of the native fauna (and thus whether it should be there in the first place), and if so whether it is artificially depleted or overabundant (i.e., below or above the perceived norm of abundance). For example, the forest cobras of São Tomé Island in the Gulf of Guinea were long believed to represent an introduced subpopulation of the mainland cobra (*Naja melanoleuca*), presumed to negatively affect native wildlife and thus considered for eradication, until phylogenetic and historical analyses revealed that they are in fact a native endemic species (*N. peroescobari*), likely to play an important role in the control of invasive rodents [18]. Conversely, Gulf groupers (*Mycteroperca jordani*) were considered naturally rare throughout their range in the Gulf of California, and believed to be resilient to ongoing levels of exploitation, but historical records and interviews of old fishers demonstrate that it has been substantially depleted through past overfishing, and that its fishery needs to be carefully managed [19].

The growing awareness of the pervasiveness of the shifting baseline syndrome [4–10], and the subsequent development of historical ecology as an applied discipline [20] translate into rapidly expanding data regarding the extent to which individual species or their subpopulations have been impacted by human activities. However, there is currently no framework for bringing all of it together into a standardised way, which can be used for contrasting human impacts across species and across regions. Here, we propose such a framework, a method for classifying populations according to the extent to which they have been impacted by human actions, what we call "EPOCH assessments" (from Evaluation of POpulation CHange).

EPOCH assessments are related to three existing frameworks: the IUCN Red List of Threatened Species [21], the Living Planet Index [22,23] and the IUCN Green List of Species [16]. The Red List assessments are classifications of species according to their risk of extinction [21]. They reflect human impacts, but only those in the recent past (past 10 years or three generations, whichever is longer; Supplementary Material), meaning that species may be at low risk of extinction (i.e., classified as Least Concern) even if strongly affected by past human actions (e.g., southern right whale *Eubalaena australis*, strongly depleted by whaling more than three generations ago [24]). The Living Planet Index is an aggregated measure of species' local population trends [22], but again it only considers recent population changes given that (for pragmatic reasons related to data availability) it takes year 1970 as the baseline. The Green List is a new framework for quantifying species recovery and conservation success [16,25]. By going beyond avoiding species' extinctions, aiming for viable and ecologically functional populations across species' indigenous range, it places recovery targets in a broader historical context. Potential dates being considered for the definition of the indigenous range include 1500 (prior to the European expansion) and 1750 (the start of the industrial era) [16], but the discussions in this regard are still ongoing, given that even baselines set several hundred years before present could underestimate impacts for those species and regions that were affected previously [26,27].

Here, we aim to evaluate the cumulative impact of human actions on species' abundances and distributions over even longer time periods. In practice, an EPOCH assessment consists of classifying a population (whole species or an infra-specific subpopulation) into one of 11 proposed categories, reflecting the extent to which its population size has changed (declined or increased) in relation to a reference state without human impacts. Rather than defining a specific date as reference, we propose that the baseline should be tailored to each population, by making the best use of the available information while taking into account the specific history of known impacts on the population. As an illustration, we apply this framework to the bowhead whale (*Balaena mysticetus*), a widespread species with wide geographic variation in the history of human impacts.

Defining the baseline

EPOCH assessments can be undertaken at the level of whole species, or at the level of infra-specific subpopulations. Subpopulations need not be discrete evolutionary units (e.g., subspecies), but should be spatially defined (e.g., a given country, a particular oceanic region) and ideally demographically independent (such that changes in one subpopulation have little effect on the demography of others; corresponding broadly to the concept of a 'stock' in fisheries sciences [28]). For simplicity, we use throughout the term 'populations' to refer to assessment units (whole species or infra-specific subpopulation), with 'population size' referring to the number of all individuals in the assessed unit.

An EPOCH assessment involves contrasting a population with a reference state, but the choice of this baseline is not necessarily straightforward. First, species' ranges and abundances change over time, both because of human impacts and through natural environmental variation, meaning that different conclusions will be reached regarding the current state of a population depending on the baseline against which it is contrasted (e.g., domestic sparrows *Passer domesticus*, are non-native to England in relation to 6 Kya baseline [29], while strongly depleted in contrast to a 1976 baseline [30]). Furthermore, there is wide variation in the history of anthropogenic impacts across regions (e.g., of the onset of commercial whaling across oceanic basins [31]), as well as across species within a given region (e.g., of the onset of commercial whaling of right versus blue whales in the North

Atlantic [31]). One option is to set the baseline as early as possible, such that it precedes all impacts for all populations. However, given that impacts started millennia ago [32], this creates two challenges: it places the baseline in eras with non-analogous environmental conditions, meaning that contrast with the baseline reflects not only human impacts but also natural change; and it reduces the likelihood that there will be adequate data on which to base the assessments.

Here, we define the baseline not as a date, but as a conceptual reference state: the population size expected today in the absence of human actions. This is a theoretical counterfactual scenario of "what would have happened if humans had not interfered", conceptually equivalent to a 'virgin' or unexploited stock in fisheries sciences [33]. By definition, then, changes in relation to this baseline measure the cumulative extent of human impacts on population size.

In practice, EPOCH assessments will frequently involve contrasting current abundances or distributions with those at a period prior to (main known) anthropogenic impacts, but this will be tailored to the specific population being assessed. For example, assessing large baleen whales will involve contrasting current population sizes with estimates of what they were prior to industrial whaling [34], which for bowhead whales (*Balaena mysticetus*) means going back to 1800 for the Sea of Okhotsk subpopulation, and to 1600 for the East Greenland–Svalbard–Barents Sea subpopulation (see below). Conceptually, such dates are not the baselines themselves; instead, going back to them is a means for estimating what the population size would (or, more accurately, might) be today without whaling.

For populations that started being impacted when environmental conditions were very different from today's, there may not be a suitable pre-impact reference date. For example, estimating the baseline for the extinct greak auk (*Pinguinus impennis*) along the European coast would involve using the best available information to model what its distribution and abundance would be in today's climate, rather than simply by reconstructing its Paleolitic, pre-exploitation distribution [35]. Accordingly, changes driven by purely natural processes (e.g. population decline of Montserrat oriole, *Icterus oberi*, subsequent to a volcanic eruption [36]) should not be considered in EPOCH assessments (unlike what happens in the IUCN Red List, where natural changes are integrated in assessments of extinction risk).

EPOCH assessments may also involve spatial rather than temporal contrasts, by using abundance or occurrence in areas of lower impact as means to estimate what the population size would be today in areas that have been more heavily impacted. For example, Maroo and Yalden used densities from relatively intact forest habitats in Białowieża National Park in Poland to infer population sizes of mammal species in Britain prior to large scale deforestation [37]. Another form of inference involves extrapolating from better to lesser well-known species. For example, Monsarrat and colleagues took advantage of the better historical information available for the North Pacific right whale (*Eubalaena japonica*), whose industrial exploitation started in the mid-1800s, to estimate the pre-whaling distribution and abundance of its North Atlantic congeneric (*E. glacialis*) whose exploitation started much earlier and is thus much less well documented [38,39].

In summary, the best approach for defining the baseline should be tailored to the specific population being assessed, taking into account its known history of human impacts, and making the best use of the available information. A one-size-fits-all temporal baseline at a given date is not needed or indeed useful, because our aim is not to understand changes since that date, but to investigate the extent of overall change in population size attributable to anthropogenic impacts.

Categories of population change

If current and baseline population sizes could be quantified precisely, comparing the two would be a simple matter of expressing the former as a percentage of the latter. In practice, however, the baseline population size (and often also the current one) will seldom be known. Nonetheless, there may still be sufficient data to make a judgement of the broad relationship between the two, and thus classify populations into different categories of change in relation to the baseline. We are here inspired by the IUCN Red List: a framework for classifying species into broad threat categories even when it is not possible to quantify extinction risk precisely.

Our proposed EPOCH classification system (Figure 1) includes 11 categories, ten of which are defined as intervals of percentage of population change in relation to the baseline. Little Changed (between 30% decline and 30% increase) applies to populations for which either there are no known human impacts, or there are good reasons to assume such impacts did not cause substantial (>30%) population change. Five categories apply to populations for which there is evidence of substantial depletion attributable to human activities: Moderately Depleted (30-60% decline), Highly Depleted (60-80% decline), Severely Depleted (80-95% decline), Nearly Extirpated (95-100% decline) and Extirpated (100% decline). The thresholds for these categories were selected to give increasing resolution (i.e. the classes become narrower) as populations approach extirpation (Figure S2), while matching as possible those of the IUCN Red List's to facilitate integration of the two frameworks (see Supplementary Materials for more details). Conversely, thresholds for the four categories of substantial increase give higher resolution to lower rates of increase: Moderately Increased (30-100% increase), Highly Increased (100-1000% increase), Severely Increased (>1000% increase), and Newly Present. The last of these categories applies to established (self-generating) populations whose presence can be attributed to humans, irrespective of the intention (or lack thereof) of the introduction process. Hence, it includes alien populations (invasive or not) as well as populations translocated for conservation purposes (e.g. kakapo *Strigops habroptilus* translocated to predator-free islands in New Zealand [40]; Figure 1, Table S1). The final category, Undetermined, applies to populations for which it is plausible that they were affected by human activities (i.e. population change likely ≠ 0%), but for which it is not possible to assess if this has resulted in substantial change (i.e., populations for which it is not clear if change ≥ 30% decline; and those for which it is not clear if change ≥ 30% increase).

EPOCH assessments in practice

Ideally the data underpinning an EPOCH assessment consists of a census of the whole population today and prior to human impacts. In practice, such data seldom – if ever – exist. Instead, estimates of current as well as baseline population sizes, or the relationship between the two, need to be inferred from the best available data (Table S1).

Useful data sources include population time series, which in a few rare cases come from whole population census. For example, censuses of wandering albatrosses *Diomedea exulans* on Bird Island show that the population has declined by about 74% since the early 1960s [45]. Much more commonly, trends are obtained from measures of relative abundance, for example Catch Per Unit Effort data indicate that black musselcrackers *Cymatoceps nasutus* declined by more than 30% in South Africa between ca. 1960 and 2009 [44]. Other proxies of change in total population size come from data on changes in spatial extent, for example in range area (e.g. a >50 fold increase in the range of the Great-tailed grackle *Quiscalus mexicanus* in the United States since 1880 [41]), or in linear extent (e.g. a 71% reduction from the 1870s to 2015 in the linear river extent occupied by the Indus river dolphin *Platanista gangetica minor* [50]). Some of these proxies can come from comprehensive spatial datasets such as atlases [51], but more commonly they correspond to generalisations from known spatial records, for example through convex polygons around known records [52] or species' distribution models combining field records and environmental information [53].

These are the same proxies used in the IUCN Red List for estimating or inferring past population trends to assess extinction risk, but at deeper temporal scales. Given that conventional ecological records rarely go back more than just a few decades [54], EPOCH assessments require mobilising a broader set of data sources, not only as potential sources of records on species, past occurrences or abundances, but also for reconstructing past environmental conditions and the timeline of human impacts. These include: oral histories (e.g., fishers' anecdotes, to understand the timeline and extent of decline of the Gulf grouper *Mycteroperca jordani* [19]); records from extractive industries (e.g. whaling log books, to reconstruct the pre-exploitation distribution [55] and abundance [38] of right whales); historical records (e.g., from letters, journals, diaries and books, to reconstruct the pre-European distribution of South African mammals [56]); archaeological records (e.g., archaeozoological assemblages from New Zealand, to investigate the impacts of pre-European Maori exploitation on populations of marine species [57]); palaeontological data (e.g. pollen, to reconstruct the past extent of European forests and the timeline of their decline [58]); and genetic data (e.g. genetic diversity, to shed light on the timing and extent of demographic declines in terrestrial vertebrates [59]). As different types of data sources have different strengths and limitations, a better understanding of population change comes from combining multiple lines of evidence while understanding the limitations of each data type [10].

The antiquity of human impacts in many regions means that it will rarely be possible to estimate population change in relation to a perfect baseline of complete absence of human impacts. Pragmatically, EPOCH assessments should approach this theoretical baseline as closely as feasible based on the available information. This may mean, for example, using a relatively recent population trend to estimate population change even if earlier impacts are suspected but poorly documented. At the very least, this helps to anchor the baseline in anticipation of future changes. In any case, assessments must make explicit the approach employed for estimating change in relation to the baseline, both as justification of the assessment and to provide a basis for future revisions as new information becomes available.

Dealing with uncertainty

Even though the categories of population change are broad (Figure 1), a paucity of available data on past population status, environmental conditions or human impacts will render difficult the categorisation of many species and subpopulations. There may, for example, be evidence of population decline, but uncertainty regarding the exact magnitude of such change (e.g. historical records detecting a change in abundance from "common" to "rare" [19]). Stepping further back in time brings substantial additional uncertainty, not only because data inevitably become scarcer, but also because the casual links between human impacts and population change can become more difficult to ascertain or confirm. Indirect effects are particularly complex to take into account, for example cascading effects such as increases in mesopredator populations when large predators have been extirpated (e.g., red fox *Vulpes vulpes* in Britain [37]).

Climate variation poses particular challenges when attempting to distinguish natural from anthropogenic change. For example, thousands of bowhead whales *Balaena mysticetus* apparently were killed in the Gulf of Saint Lawrence and Strait of Belle Isle in the 16th and 17th centuries, but they no longer occur there. It is not clear whether their current absence from this region reflects a range contraction after the end of the Little Ice Age or extirpation caused by whaling (or a combination of both) [60]. These challenges only become more pronounced when stepping even further back in time, as testified by the still ongoing debate on the relative effects of human hunting versus climate change in Pleistocene megafauna extinctions [61,62].

We encourage making uncertainty explicit, by indicating not only the most likely category based on the available information, but also specifying other plausible categories, if applicable (see examples in Table S1). We also recommend erring on the side of underestimating rather than overestimating change and thus past human impact, particularly in assessments based on more uncertain data (such as historical anecdotes). Following the same principle, populations for which no impacts are known, or their magnitude is believed not to have caused substantial change, should by default be placed in the Little Changed category. In contrast, the Undetermined category is reserved for situations for which it is plausible that the population has been affected by human activities, but it is not possible to ascertain whether this has resulted in significant change in population status (e.g., see Omura's whale [49] in Table S1).

Worked example: bowhead whale

For widespread species, the timeline and intensity of human impacts can vary substantially across subpopulations. In these cases, the best way of capturing this variation is through infra-specific EPOCH assessments. The collective value of these assessments will be much increased if subpopulations are defined to ensure that they do not overlap geographically while covering the entire historical range of the species, in which case they can be mapped to show levels of human impact across the species' range.

As an illustration, we present here (Figure 2) EPOCH assessments for subpopulations of the bowhead whale (see Supplementary Materials for details and additional references). Because of its high oil yield and valuable baleen, the bowhead whale was one of the most prized targets of industrial whaling, but the timeline of its exploitation and recovery (or lack thereof) is highly variable across its circumpolar range. For example, bowheads in the East Greenland–Svalbard–Barents Sea region were exploited commercially for three centuries, from the early 1600s to the early 1900s. Despite subsequent protection, the population has not recovered since: just a few hundred remain [46] out of a pre-whaling population estimated at ca. 50,000 individuals [47], and we thus classify it as Nearly Extirpated. In contrast, industrial exploitation in the Bering–Chukchi–Beaufort Seas took place in just a few, more recent decades, from 1848 to 1921. Although this subpopulation also collapsed from over-exploitation, it has since recovered to levels estimated to be close to the original ca. 20,000 individuals [63], and we thus consider it Little Changed.

Subpopulations are units of assessment, but that does not mean they are necessarily homogeneous. In the case of the bowhead whale, we distinguish within the historical range of the Eastern Canada–West Greenland subpopulation (ECWG) the region encompassing the Strait of Belle Isle and Gulf of St. Lawrence (BISL). Indeed, whereas the broader ECWG population seems to have partially recovered from whaling and is now Moderately Depleted, bowheads have not re-occupied the BISL region to where they previously migrated [60] and we thus map it as Extirpated in this area (but see above for the potentially confounding effects of climate change, and [64] for recent observations south of the usual recent Arctic range).

Combining subpopulation assessments into a species-level assessment should make the best use of the available information. In the case of the bowhead whale, a status of Little Changed is obtained if change in overall range extent is used as a surrogate for change in population size (9% decline), whereas combining information on the historical range size of each subpopulation with its category of population change results in a classification of Moderately Depleted (ca. 58% decline), while using estimates of current and past population size for each subpopulation yields a Highly Depleted status (ca. 66% decline; details in Supplementary Material; Table S2). As this last approach is the one that makes the best use of available data, Highly Depleted is the classification that prevails.

Understanding the degree of depletion of bowhead whales across populations is not only key to gauging the magnitude and distribution of past human impacts on the species (Figure 2), but it is also key to understanding the structure and functioning of Arctic ecosystems, thus to better predict how they will respond to future changes. For example, bowhead depletion is believed to have released large quantities of zooplankton biomass, with cascading effects towards a foodweb dominated by pelagic fishes and planktivorous seabirds [65,66]. In places where bowhead populations are recovering, a reverse ecosystem shift may be under way, with declines in the populations of some species [65]. If not placed in an historical context of bowhead overexploitation (equivalent to using the present as baseline), such ecosystem changes could be misattributed to other, more recent, human impacts (e.g., climate change, pollution). The historical context is also key to the definition of appropriate future conservation and management goals for bowheads, even as Arctic ecosystems are foreseen to change dramatically due to climate change. For example, even though the core area of suitable habitat for bowhead whales is predicted to decline by half from what it is now by the year 2100 due to climate change [67], this does not mean the bowhead population will necessarily decline in relation to today. Instead, the populations that are currently the most depleted may still have margin for substantial increase as they recover from overexploitation.

Conclusions

EPOCH assessments will be more easily carried out for species for which human impacts are better documented, including those most visible in the historical record (e.g., large charismatic mammals [68]), those with good records of recent industrial exploitation (e.g., marine mammals and large fishes [34,69]) and those that fossilise well (e.g., molluscs [70]). This framework is nonetheless designed to integrate a wide diversity of data types, including information with relatively high levels of uncertainty, to ensure that it can also be applied in circumstances of relative data paucity. Furthermore, it is applicable even to species for which nothing is known about their past: the baseline can be anchored today, as the reference in future EPOCH assessments.

The immediate application of EPOCH assessments is as a framework for reviewing and synthesising evidence on how human actions have changed the abundance and distribution of whole species or of subpopulations. Assessments can then be combined across populations within a given area, and across regions, to investigate taxonomic or spatial variation in human impacts (in a similar way to using Red List assessment to investigate taxonomic and spatial variation in extinction risk; e.g. [71]). When combined across multiple species, or applied to species known to have key functional roles in ecosystems [72], this new approach will also contribute to understanding how the composition and structure of ecosystems has changed in response to human activities, applicable for example to assessments under the IUCN Red List of Ecosystems [73]. By providing a clearer picture of the composition and structure of intact ecosystems, EPOCH assessments can thus contribute to understanding of the ecological and evolutionary mechanisms that have shaped biodiversity [74].

These insights obtained from the incorporation of baseline data into population status assessments will in turn support conservation and management decisions, at both the species and the ecosystem level. EPOCH assessments themselves are merely informative, not prescriptive, given that population baseline sizes and distributions do not automatically translate into achievable or even desired conservation targets in the world as it is today or as it is bound to become in the foreseeable future [75]. Indeed, conservation targets must necessarily integrate other factors such as ecological interactions, economic costs and benefits, technical feasibility, and societal acceptance. This said, perceptions of whether species belong to the native fauna of a region, and if so whether they are considered depleted or overabundant in relation to the expected norm, and thus if ecosystems are seen as intact or degraded, can and do feed into the scientific argument underpinning many conservation and management interventions, as well as affecting public acceptance of, and support for, such interventions [9].

Hence, at the single-species level, assessments of the cumulative level of population change through time in response to both ancient and recent human impacts can help to set ambitious but realistic targets for the recovery of populations, for example in the context of Green List of Species assessments [25,27], as well as to provide reference points to define sustainable exploitation levels, for example in fisheries [33]. Combined into multi-species indicators, EPOCH assessments can become the basis of indices of ecosystem degradation, help to identify areas of particularly intact communities (e.g., under the C criterion of the Key Biodiversity Areas Standard [76]), as well as inform targets for wider ecosystem recovery, for example as part of restoration [77] or rewilding efforts [78]. With the United Nations having just declared 2021-2030 the Decade of Ecosystem Restoration [79], ensuring that future conservation efforts take into account the history of past changes is more pertinent than ever.

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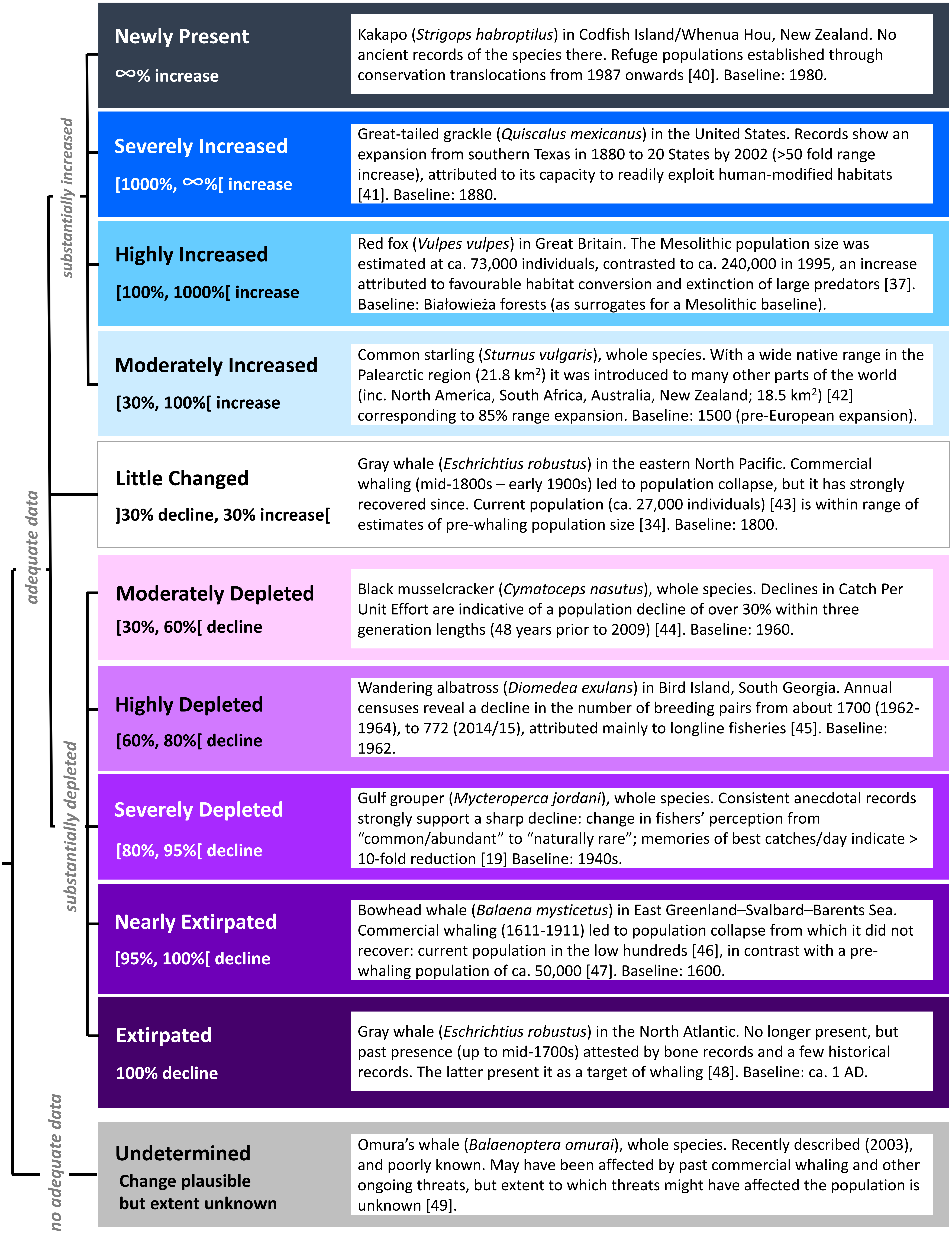
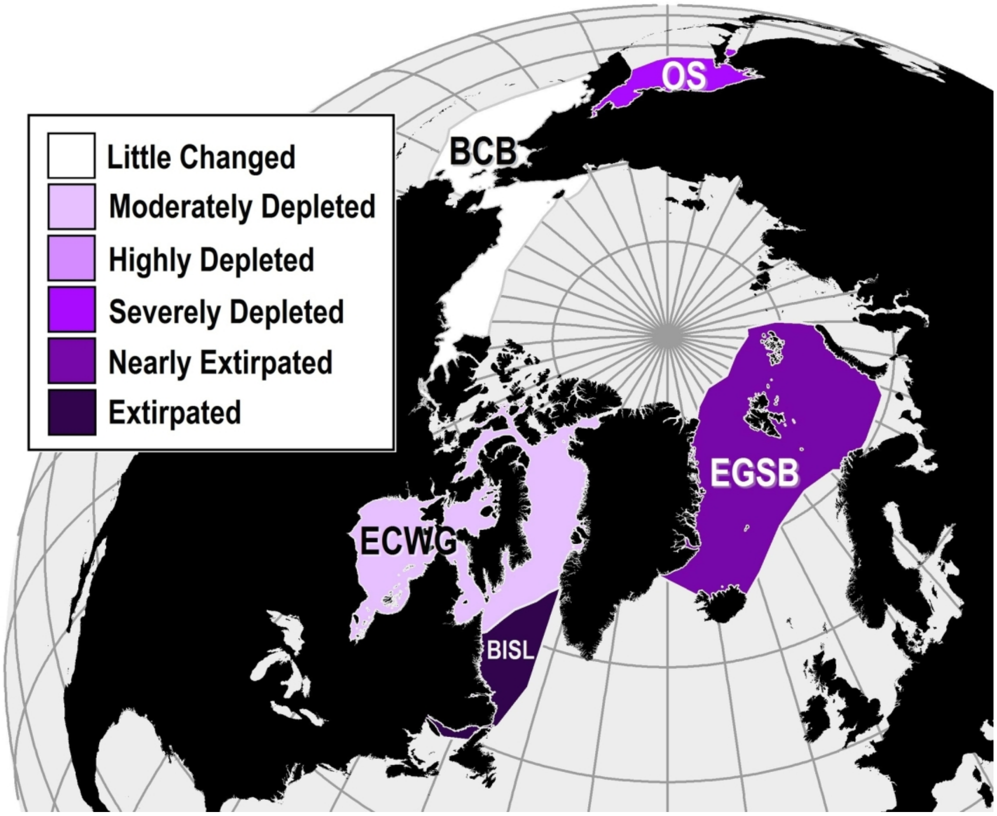
Figure captions

Figure 1: EPOCH categories of population change, with respective thresholds (percentage of change in population size in relation to a conceptual baseline in the absence of human actions) and illustrative examples (see Table S1 for more details).

Figure 2: EPOCH assessments of four subpopulations of bowhead whale (*Balaena mysticetus*): Bering–Chukchi–Beaufort Seas (BCB, Little Changed, 1800 baseline); Okhotsk Sea (OS, Severely Depleted, 1800 baseline); East Greenland–Svalbard–Barents Sea (EGSB, Nearly Extirpated, 1600 baseline); and Eastern Canada–West Greenland (ECWG, Moderately Depleted, 1500 baseline). We map separately the region of the Strait of Belle Isle and Gulf of St. Lawrence (BISL), which is part of ECWG, as it is no longer occupied (thus mapped as Extirpated). See Supplementary Materials for details.



Newly Present **∞% increase**	Kakapo (*Strigops habroptilus*) in Codfish Island/Whenua Hou, New Zealand. No ancient records of the species there. Refuge populations established through conservation translocations from 1987 onwards [40]. Baseline: 1980.
Severely Increased **[1000%, ∞%[increase**	Great-tailed grackle (*Quiscalus mexicanus*) in the United States. Records show an expansion from southern Texas in 1880 to 20 States by 2002 (>50 fold range increase), attributed to its capacity to readily exploit human-modified habitats [41]. Baseline: 1880.
Highly Increased **[100%, 1000%[increase**	Red fox (*Vulpes vulpes*) in Great Britain. The Mesolithic population size was estimated at ca. 73,000 individuals, contrasted to ca. 240,000 in 1995, an increase attributed to favourable habitat conversion and extinction of large predators [37]. Baseline: Białowieża forests (as surrogates for a Mesolithic baseline).
Moderately Increased **[30%, 100%[increase**	Common starling (*Sturnus vulgaris*), whole species. With a wide native range in the Palearctic region (21.8 km^2) it was introduced to many other parts of the world (inc. North America, South Africa, Australia, New Zealand; 18.5 km^2) [42] corresponding to 85% range expansion. Baseline: 1500 (pre-European expansion).
Little Changed **]30% decline, 30% increase[**	Gray whale (*Eschrichtius robustus*) in the eastern North Pacific. Commercial whaling (mid-1800s – early 1900s) led to population collapse, but it has strongly recovered since. Current population (ca. 27,000 individuals) [43] is within range of estimates of pre-whaling population size [34]. Baseline: 1800.
Moderately Depleted **[30%, 60%[decline**	Black musselcracker (*Cymatoceps nasutus*), whole species. Declines in Catch Per Unit Effort are indicative of a population decline of over 30% within three generation lengths (48 years prior to 2009) [44]. Baseline: 1960.
Highly Depleted **[60%, 80%[decline**	Wandering albatross (*Diomedea exulans*) in Bird Island, South Georgia. Annual censuses reveal a decline in the number of breeding pairs from about 1700 (1962-1964), to 772 (2014/15), attributed mainly to longline fisheries [45]. Baseline: 1962.
Severely Depleted **[80%, 95%[decline**	Gulf grouper (*Mycteroperca jordani*), whole species. Consistent anecdotal records strongly support a sharp decline: change in fishers' perception from "common/abundant" to "naturally rare"; memories of best catches/day indicate > 10-fold reduction [19] Baseline: 1940s.
Nearly Extirpated **[95%, 100%[decline**	Bowhead whale (*Balaena mysticetus*) in East Greenland–Svalbard–Barents Sea. Commercial whaling (1611-1911) led to population collapse from which it did not recover: current population in the low hundreds [46], in contrast with a pre-whaling population of ca. 50,000 [47]. Baseline: 1600.
Extirpated **100% decline**	Gray whale (*Eschrichtius robustus*) in the North Atlantic. No longer present, but past presence (up to mid-1700s) attested by bone records and a few historical records. The latter present it as a target of whaling [48]. Baseline: ca. 1 AD.
Undetermined **Change plausible but extent unknown**	Omura's whale (*Balaenoptera omurai*), whole species. Recently described (2003), and poorly known. May have been affected by past commercial whaling and other ongoing threats, but extent to which threats might have affected the population is unknown [49].



EPOCH assessments of four subpopulations of bowhead whale (Balaena mysticetus): Bering–Chukchi–Beaufort Seas (BCB, Little Changed, 1800 baseline); Okhotsk Sea (OS, Severely Depleted, 1800 baseline); East Greenland–Svalbard–Barents Sea (EGSB, Nearly Extirpated, 1600 baseline); and Eastern Canada–West Greenland (ECWG, Moderately Depleted, 1500 baseline). We map separately the region of the Strait of Belle Isle and Gulf of St. Lawrence (BISL), which is part of ECWG, as it is no longer occupied (thus mapped as Extirpated). See Supplementary Materials for details.

157x129mm (300 x 300 DPI)