Long-term Ecological Research (LTER) – network of sites revealing global patterns

Section A

i) Purpose

Most studies are short-term (< 4 years) (Peters, 2010), mainly caused by funding limitations, but these observations can explain the underlying mechanisms of long-term studies (Figure 1). The beginning of the establishment of long-term ecological research (LTER) programs was the International Biological Program (IBP) in 1964 (Lane, 1997). The main motivation for this program was the lack of scientific knowledge about anthropogenic effects on biological productivity and resources on an international level (McKee, 1970). A site at Snowdon in North Wales was chosen as part of the IBP program and was monitored from 1966 to 1977.

ii) Snowdon description and measurements

In 1992, the Environmental Change Network (ECN) was established in the UK, to create a network of LTER sites, using ECN sampling protocols (Lane, 1997). Snowdonia was chosen to be an ECN site in 1995 because (i) it has well-documented historical data, (ii) special montane habitat and (iii) highest annual rainfall (Morecraft et al., 2009). The total of 712 ha is used for measurements following ECN sampling protocols as well as additional measurements for other networks (e.g. UKAEAP, Welsh Air Quality Forum/Ricardo-AEA) and non-ECN measurements (e.g. snow level recording, phenology, arctic-alpine plants). From 2005, Nant Teyrn freshwater site was established within the ECN site.

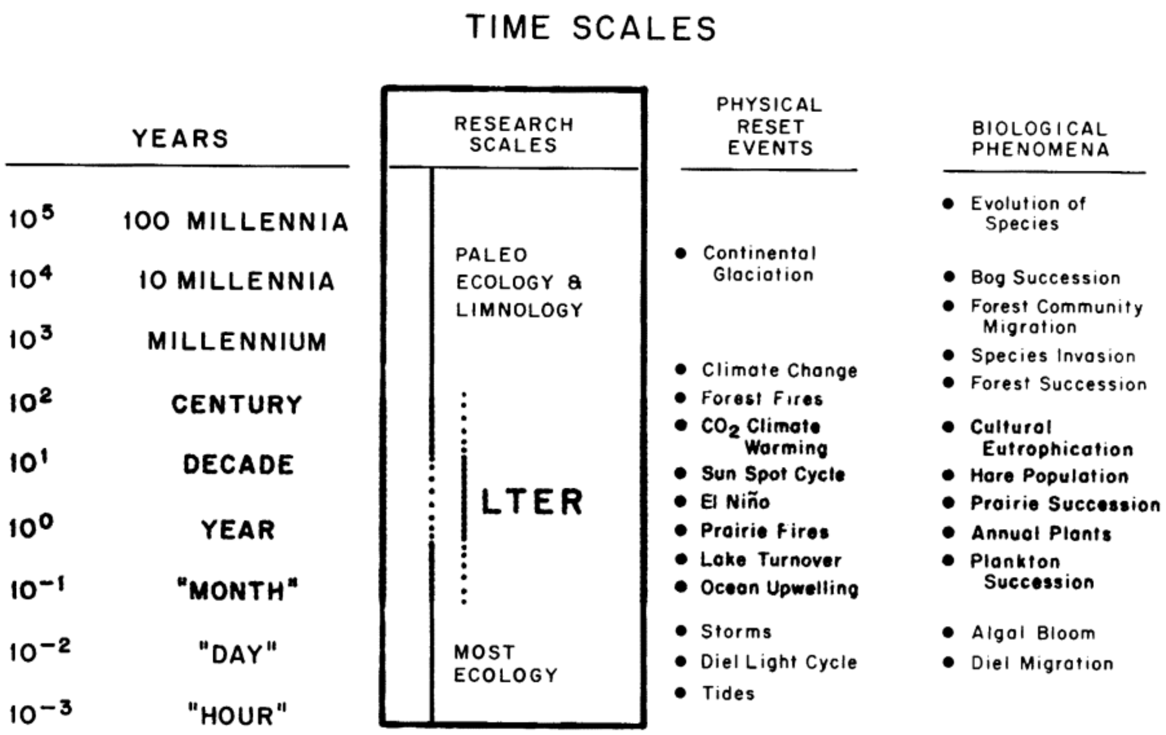

Figure 1. LTER enables the monitoring of abiotic and biotic factors on a large time-scale (Magnuson, 1990). These revealed many time lags of ecological response of anthropogenic effects such as lake turnovers and grazing. Short-term studies can fail to discover these patterns.

Trends revealed at Snowdon

Studies have concentrated on vegetation (McGovern et al., 2011), soil composition, chemistry and microbial activity (McGovern et al., 2013 and 2014). The main pattern that these studies have shown is that despite the decline in sulphur and nitrogen emissions around the UK, air pollution has a detrimental effect on Snowdonia. The slight decline in soil pH suggest further acidification rather than soil recovery (McGovern et al., 2013). The effect of grazing and rapid grazer removal has also been shown to affect vegetation recovery at Llyn Llydaw. Despite a 50% decrease in sheep numbers since 1995, the number of feral goats increased by fourfold (Dick et al., 2016). Complete grazing removal led to nitrogen rich soil, dominated by bacteria and increased NO_3^- leaching (McGovern et al, 2014). There are also differences of brown earth and peaty podzol and the soil chemistry altered by grazing removal. The increasing grass:forbs ratio also suggest a vegetation shift to acidity tolerant species (McGovern et al., 2011).

Section B

i) Snowdon in the ECN network

The main aim of LTER network is to enable data analysis on regional, national and international levels. Despite the Snowdonia ECN site supporting the highest number of butterfly species compared to the other ECN sites (Morecraft et al., 2009), both carabid species and overall species diversity has been declining. It also has the highest nitrogen deposition compared to other UK grassland sites and therefore, the one of the highest rate of leaching.

ii) Coordination efforts

Collaborative effort of scientists of LTER network has led to compatible data sets on a global scale. This was enabled through the uniform sampling protocols, governmental and intergovernmental funding support and establishment of shared data storage. Global patterns on biome levels (Ponce-Campos et al., 2013) have been able to predict climate change driven changes. LTER network enabled statistically robust analysis and therefore reliable identification of sensitive and resilient habitats.

iii) Critical appraisal of freshwater lake fish population trends

Loch Leven in Scotland is an experimental ECN site in terms of angling activities (Winfield et al., 2012), lake management (May et al., 2012) and its eutrophication. Historically, 11 native fish species were recorded of which three species have become locally extinct, and one non-native species (rainbow trout, *Oncorhynchus mykiss*) was introduced in 1993 (Winfield et al., 2012). By 2008, only five fish species were recorded.

The study used historical data and gill netting and hydro-acoustic surveys for fish density in 2007-2008. The paper only discusses fish population trends and length measurements of brown trout, using only descriptive statistics. Brown trout *(Salmo trutta)* stock was declining since 1970 in Loch Leven, but as their number decreased, their weight increased (Winfield et al., 2012). The sample size for the length measurements was 163 fish in 2008 which was compared to data from other Scottish lakes. The lake was most abundant in perch *(Perca fluviatilis)* which showed an increase in length from 2001 to 2008, but it was is lower condition compared to other Scottish lakes' stocks (Figure 2A). Their sample sizes for perch population was 641 in 2008 and in 2001, they measured the length of 180 individuals. Major declines in the 1980s and 1990s was due to low oxygen availability and water clarity at which point the lake management reduced external phosphorus from industrial discharges and sewages by 60% (May et al., 2012). Due to this management, the water quality improved, there was an increase in *Daphnia* numbers which led to more food availability for the fish (May and Spears, 2012). Increased temperature induced by climate change at Loch Leven is expected to have an effect on micro-plankton population growth but wetter summers will have a positive effect by lowering chlorophyll *a* concentrations (Carvalho et al., 2012).

Freshwater fish in Alaskan LTER site

A study of an Alaskan LTER lake focusing on lake trout *(Salvelinus namaycush)* dynamics showed how fertiliser addition (inorganic nitrogen and phosphorus), have positive-short term effects but negative long-term effects (Lienesch et al., 2005). The lake was known to be inhabited by three other fish species (*Thymallus arcticus, Lota lota,* and *Cottus cognatus*). From 1987 until 1999, passive integrated tags were used recapture measurements for lake trout. In total 300 fish were caught by angling, measured, aged, tagged and then released. Sixty tags were lost and therefore population estimates were calculated using capture probability. The density of *Lymnaea elode*, which is the main food source or also counted intermittently throughout these years, using line transects. Non parametric methods were used for catchable size-class fish recruitment, using probability calculations. Successful recapturing enabled the calculation of weight and length gain per year. The application of additional nutrients during 1990-1994, led to increased primary production and abundance of *Lymnaea elode*, which consequently led to a significant increase in lake trout growth rate and weight (Figure 2B). These results were supported by significant one-way ANOVA tests. There was no increase in catchable size-class fish recruitment recorded (1990-1999) based on the predictions. The thicker hypoxic layer

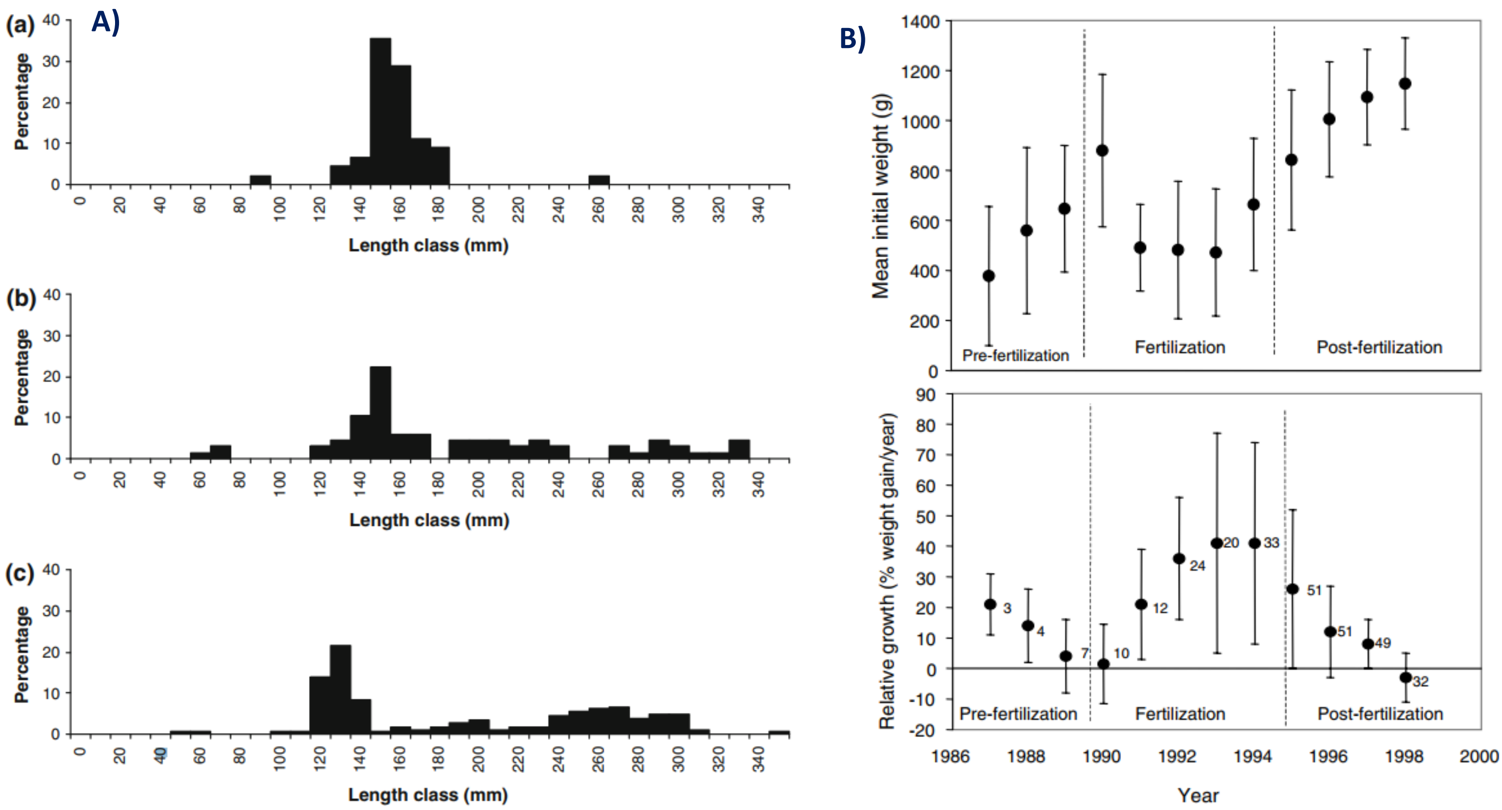

Figure 2. A) Study by Winfield et al. (2012) showing perch length distribution between 2008 (a, n=48); 2001 (b, n=67) and 1968 (c, n=180). B) Lake trout *(Salvelinus namaycush)* growth and weight from 1987 to 1999 (n=240) (Lienesch et al., 2005).

additional nutrients in lakes increase fish growth, but long-term this application leads to a collapse of the ecosystem (Lienesch et al., 2005).

Comparison

These two LTER studies showed how anthropogenic effects can have an effect on fish abundance and growth. While Winfield et al. (2012) relied mostly on historical data and did not conduct statistical analyses, Leinesch et al. (2005) carried out a more thorough experiment with larger sample sizes and therefore their results are more reliable.

National level

On a national level, Dodson et al. (2000) compared 33 LTER American lakes in terms of their primary production, area and species richness. Although significant correlation was found between lake area and fish species richness, the regression was not strong. They did not find correlation between primary productivity and fish species was unexpected compared to individual studies, but could be explained by the negative effect of eutrophication.

LTER studies of lake inhabiting fish populations, reviewed above, have shown different patterns to short-term experiments (discussed by Leinesch et al,. 2005) which are driven by lake food web systems (D'Alelio et al., 2016). LTER network enables the continuation of monitoring and experimenting which are crucial for future habitat management practices and restoration projects globally (Figure 3).

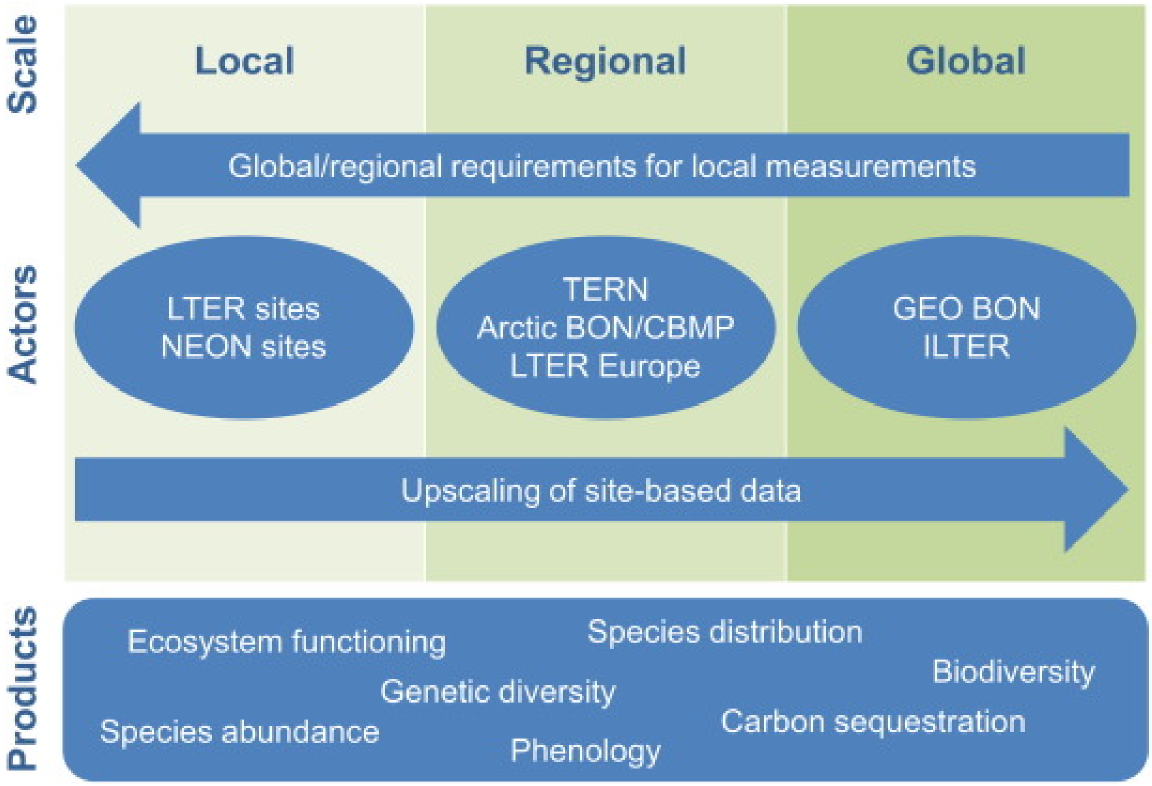

Figure 3. LTER site monitoring produces a variety of information which can be used for local, regional and global analysis (Haase et al., 2018). This system is maintained by local governments, regional networks and intergovernmental bodies.

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