IAEA Ocean Acidification International Coordination Centre OA-ICC

UNIVERSITY OF GOTHENBURG

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

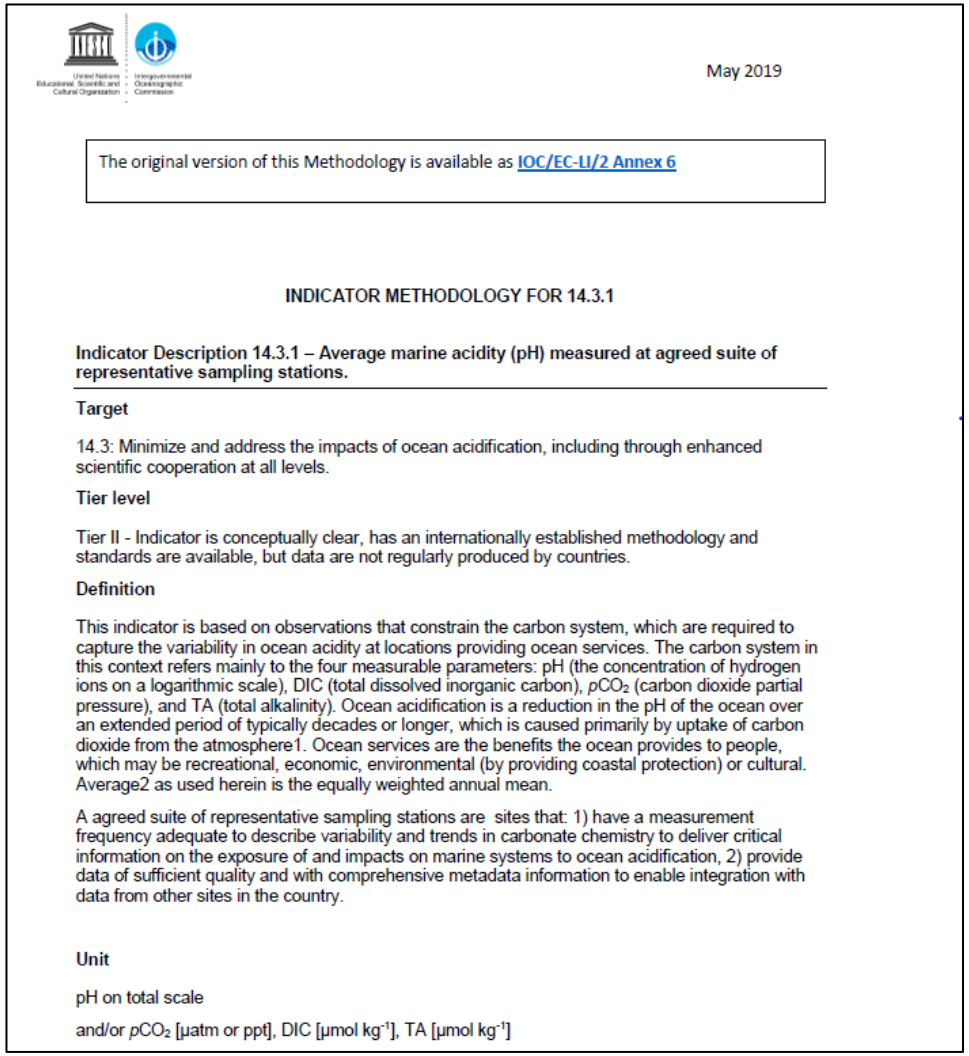
Basic training course on ocean acidification

EVT1804704

14-19 March 2022

Monitoring – How long?

Chemistry



May 2019

The original version of this Methodology is available as IOC/EC-LI/2 Annex 6

INDICATOR METHODOLOGY FOR 14.3.1

Indicator Description 14.3.1 – Average marine acidity (pH) measured at agreed suite of representative sampling stations.

Target

14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.

Tier level

Tier II - Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.

Definition

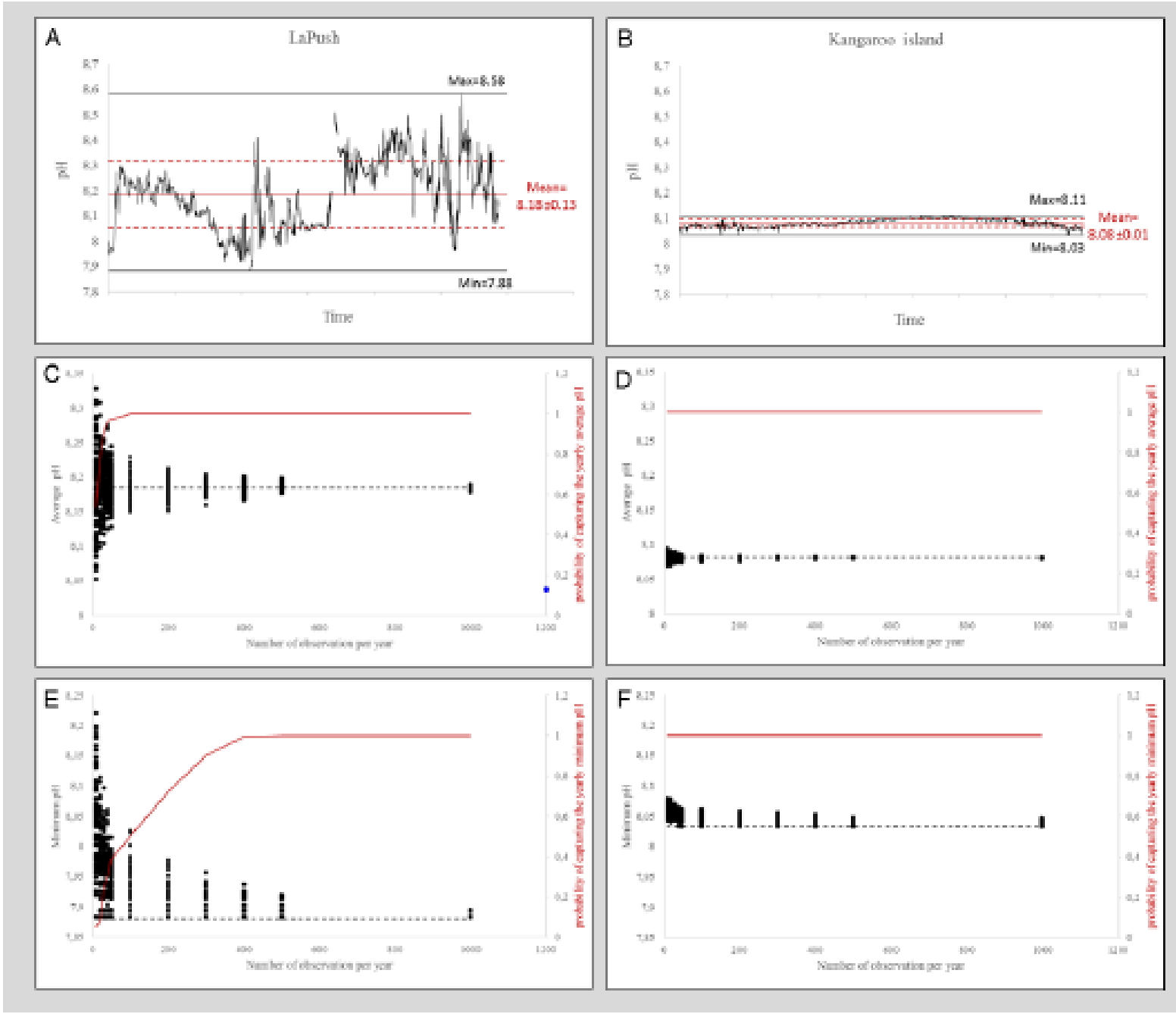
This indicator is based on observations that constrain the carbon system, which are required to capture the variability in ocean acidity at locations providing ocean services. The carbon system in this context refers mainly to the four measurable parameters: pH (the concentration of hydrogen ions on a logarithmic scale), DIC (total dissolved inorganic carbon), pCO_2 (carbon dioxide partial pressure), and TA (total alkalinity). Ocean acidification is a reduction in the pH of the ocean over an extended period of typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere1. Ocean services are the benefits the ocean provides to people, which may be recreational, economic, environmental (by providing coastal protection) or cultural. Average2 as used herein is the equally weighted annual mean.

A agreed suite of representative sampling stations are sites that: 1) have a measurement frequency adequate to describe variability and trends in carbonate chemistry to deliver critical information on the exposure of and impacts on marine systems to ocean acidification, 2) provide data of sufficient quality and with comprehensive metadata information to enable integration with data from other sites in the country.

Unit

pH on total scale

and/or pCO_2 [µatm or ppt], DIC [µmol kg^{-1}], TA [µmol kg^{-1}]


A
LaPush
Max=8.58
Mean=
8.18±0.13
Min=7.88
pH
Time
B
Kangaroo island
Max=8.11
Mean=
8.08±0.01
Min=8.02
pH
Time
C
D
E
F
Number of observation per year

Biology

GOA-ON… since 2012

GOA-ON

Global Ocean Acidification Observing Network

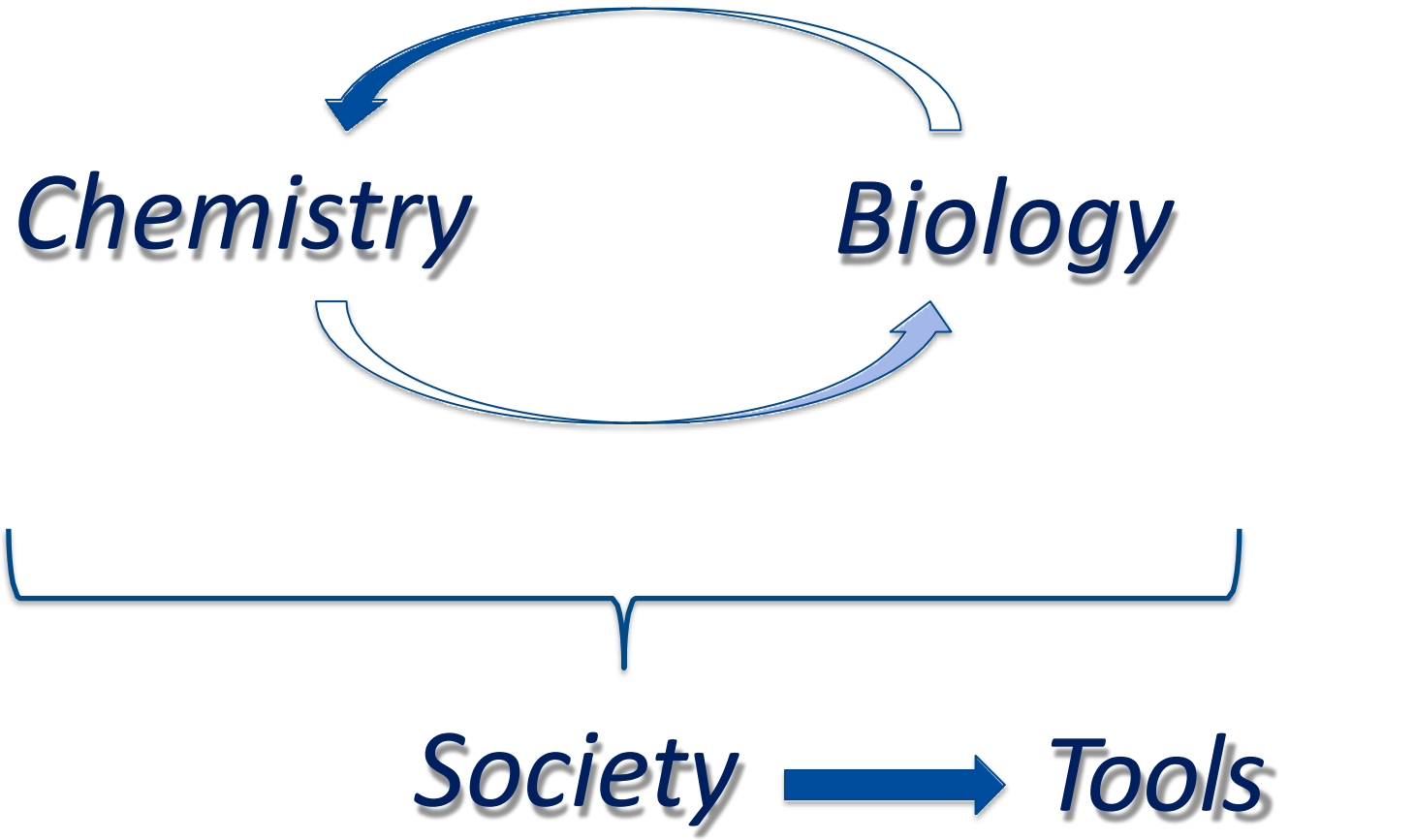
St. Andrews 2013

Seattle 2012

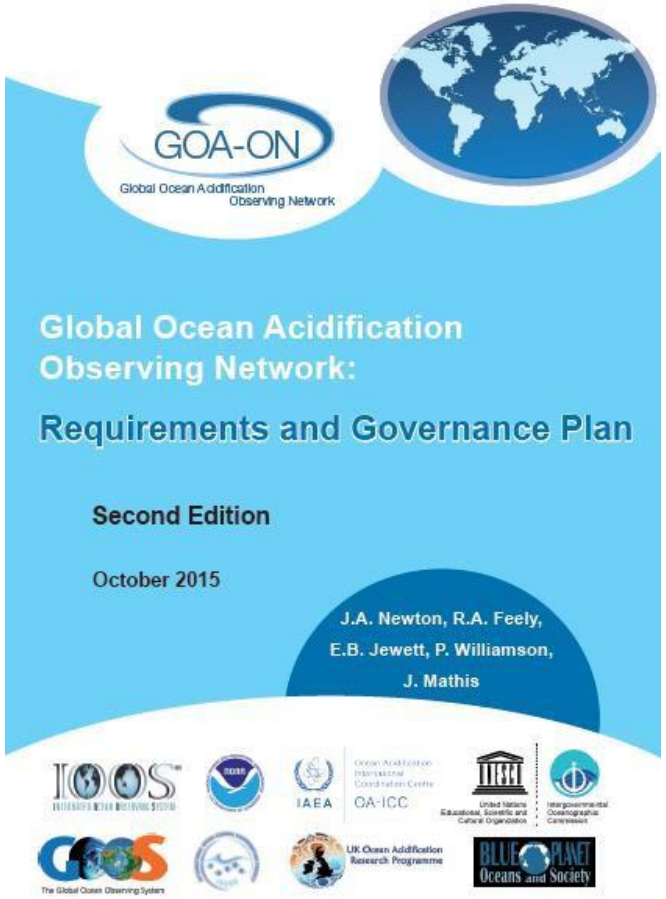
Hangzhou 2019

Hobart 2016

Importance of biology for a (chemical) monitoring network



A long list of measurements



- Level 1 measurements
- Addressing Goal 2 at the broadest scale requires the measurement of biomass or abundance of functional groups, listed below, contemporaneous with the physical and chemical measurements for Goal 1 that achieve at least 'weather' data quality.

- **Biomass/abundance of**:

o Phytoplankton

o Zooplankton

o Benthic producers and consumers (shelf seas and nearshore)

- Etc. etc. etc

Unrealistic

Comparison difficult

Biology Working Group

First meeting 2015
(virtual)

Kirsten Isensee
Sam Dupont
Nelson Lagos
Luis Valdes
Maciej Telszewski
Sinead Collins
Phil Williamson
Ulf Riebesell
Piero Calosi
Yuri Artioli
Steve Widdicombe
Philip Munday
Libby Jewett
Nic Bax
Erica Ombres

2016 – First meeting in Monaco

IAEA
International Atomic Energy Agency

GOA-ON
Global Ocean Acidification Observing Network

Three tasks identified

Task #1 - **Inform the chemical monitoring program about the biological needs** [Short term]

Task #2 – **Evaluate the needs and requirement of a Biological Monitoring Program** [Medium/Long term]

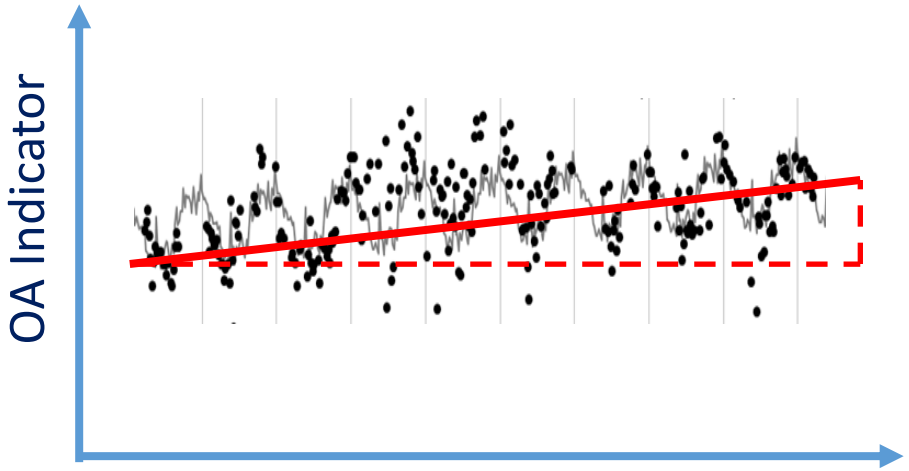
Task #3 – **Develop a theoretical framework linking chemical changes to biological response** [Medium/Long term]

2020 – Second meeting in Sweden

Task #2 – **Evaluate the needs and requirement of a Biological Monitoring Program**

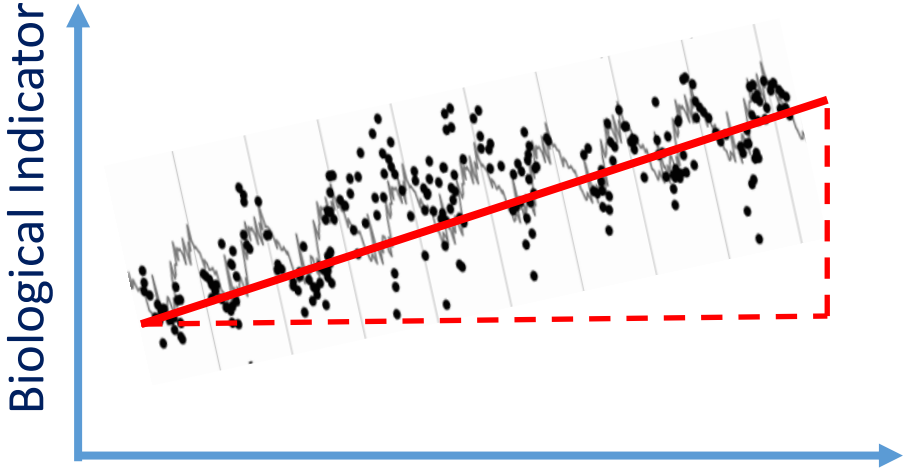
What does OA Biological Impacts monitoring look like?

Ocean Acidification Monitoring



Annual Rate of OA Indictor Change

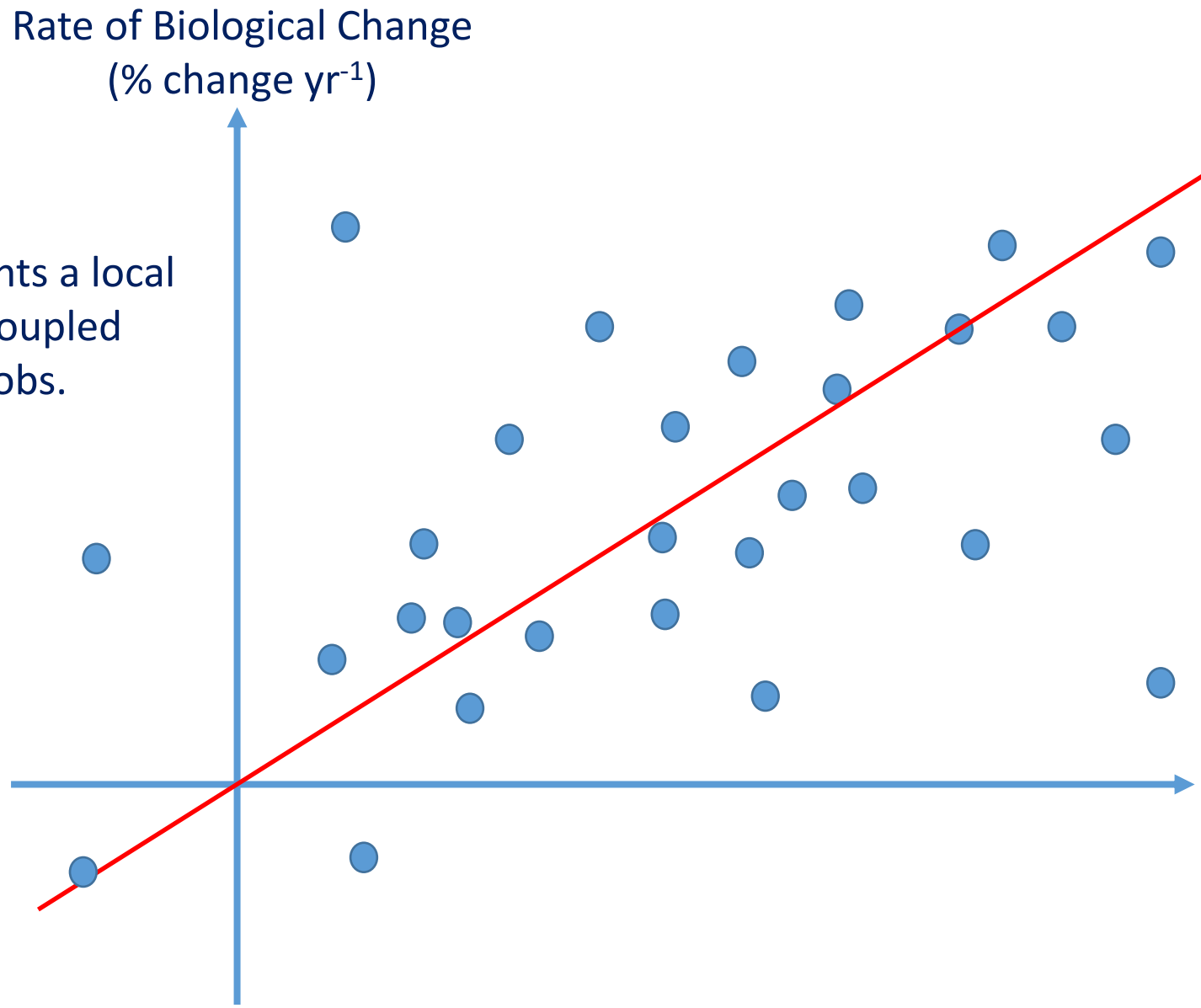
Biological Monitoring



Standardise
(% change from initial condition)

Rate of Biological Change
(% change. yr^{-1})

Expanding to a Global / Regional Comparison

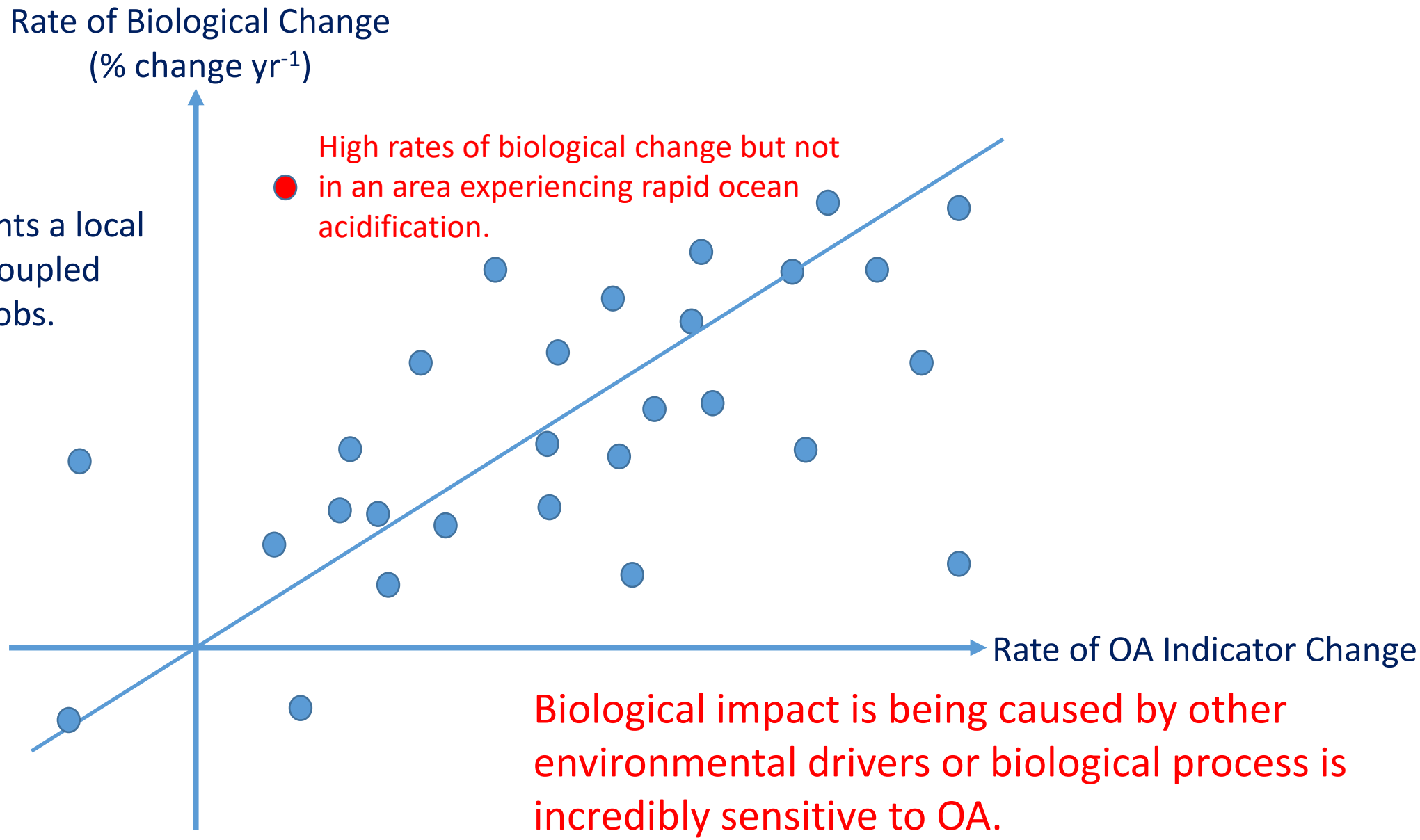


Each ● represents a local time series of coupled OA - biological obs.

With enough observations it may then be possible to generate a generic, global relationship between OA and a biological change.

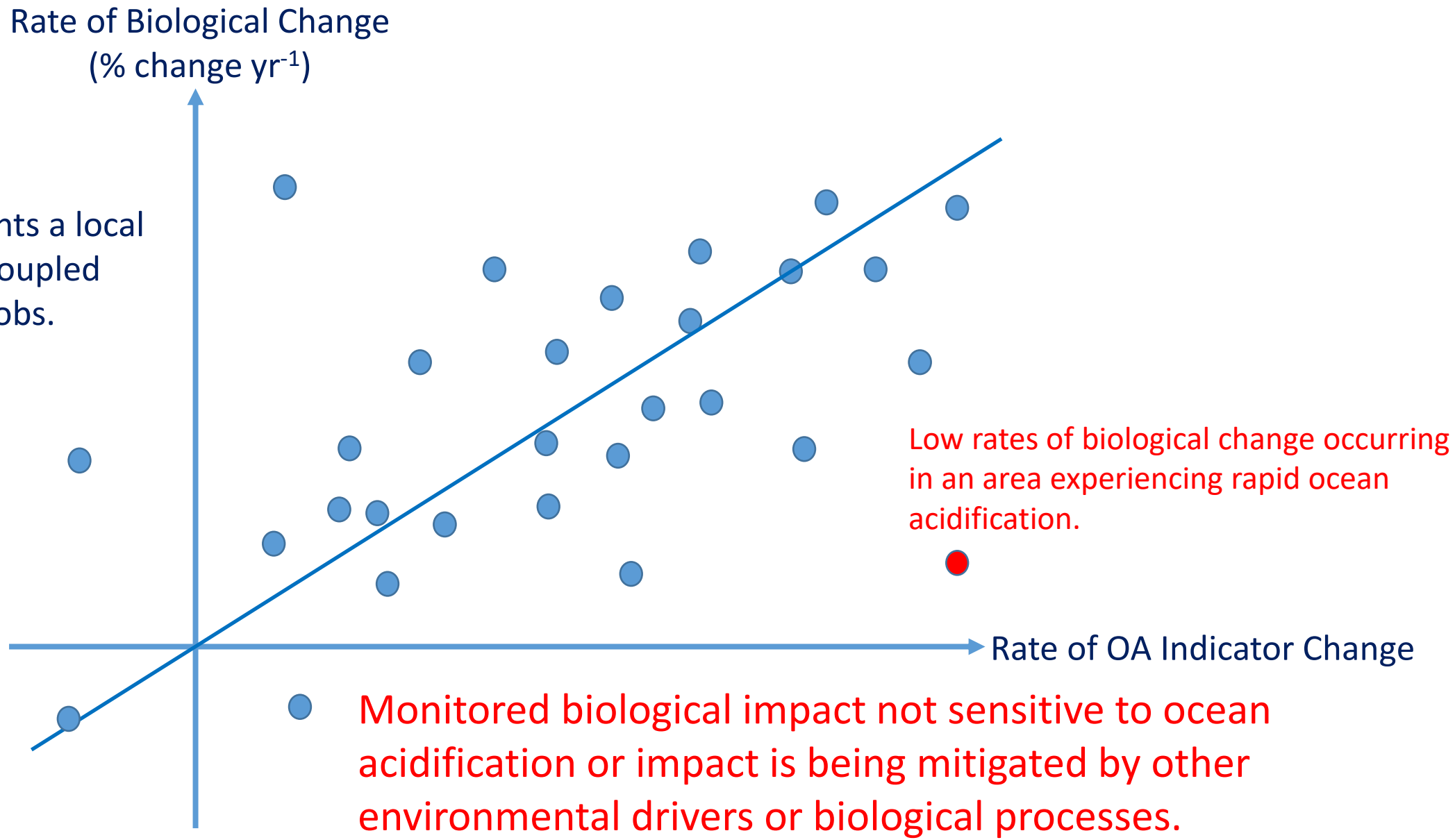
[Can be an absolute change rather than %, but be mindful of the specific OA indicator attributes, e.g. pH is log scale]

Identifying Interesting Local Phenomena



Biological impact is being caused by other environmental drivers or biological process is incredibly sensitive to OA.

Identifying Interesting Local Phenomena



- ✓ Biological monitoring is valuable in itself
- ✓ We are not here to tell you what to do !
- ✓ There are many reasons to select a site (important, co-location with chemistry, existing infrastructure, etc.)
- ✓ OK to NOT see any change (if robust data)
- ✓ This sub-module is about how to optimize your chances to see OA driven biological changes over a reasonable amount of time

Factors modulating biological rate of change

- ✓ Biological sensitivity
- ✓ Chemical rate of change

Biological sensitivity

nature ecology & evolution

ANALYSIS

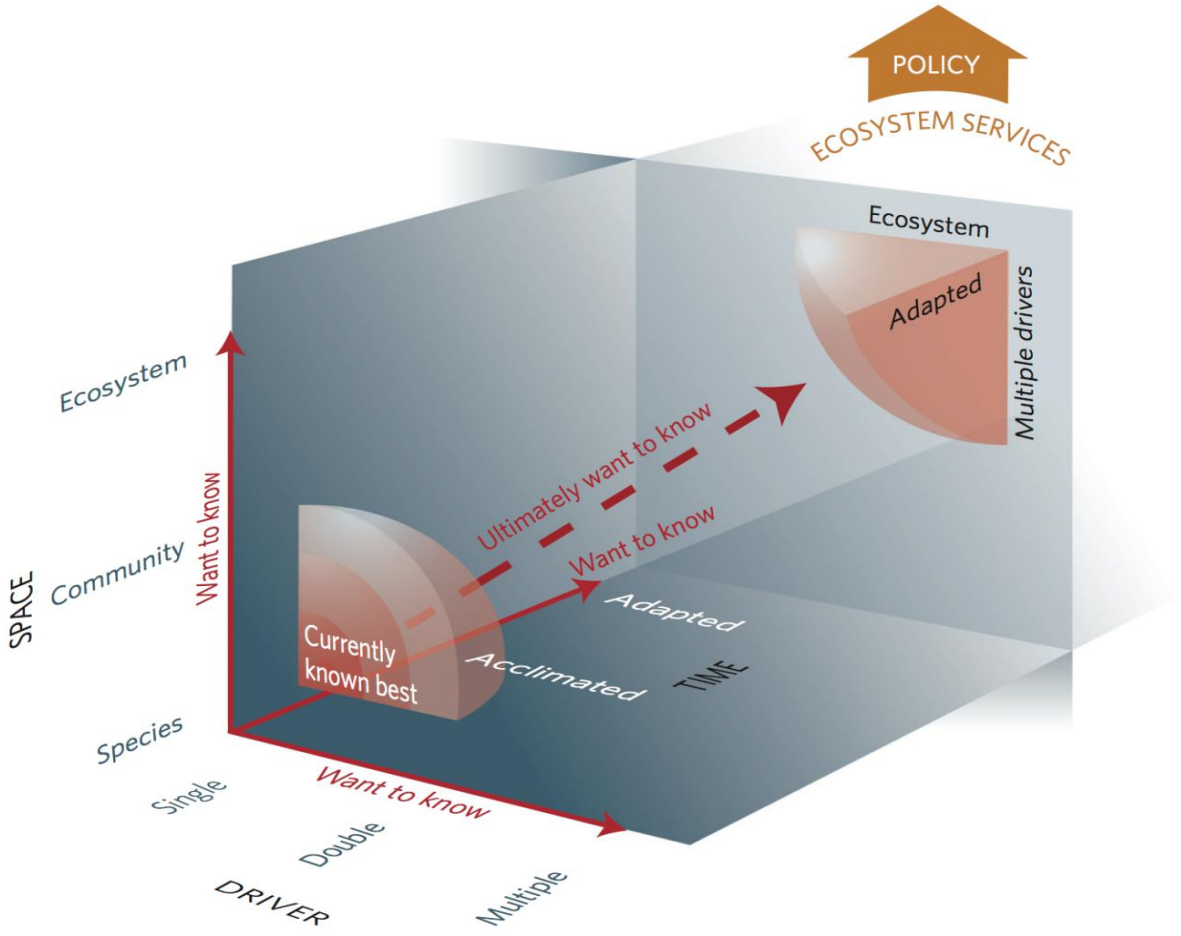
PUBLISHED: 13 MARCH 2017 | VOLUME: 1 | ARTICLE NUMBER: 0084

Species-specific responses to ocean acidification should account for local adaptation and adaptive plasticity

Cristian A. Vargas[1,2,3]*, Nelson A. Lagos[3,4], Marco A. Lardies[3,5], Cristian Duarte[3,6], Patricio H. Manríquez[7], Victor M. Aguilera[2,8], Bernardo Broitman[3,7], Steve Widdicombe[9] and Sam Dupont[10]

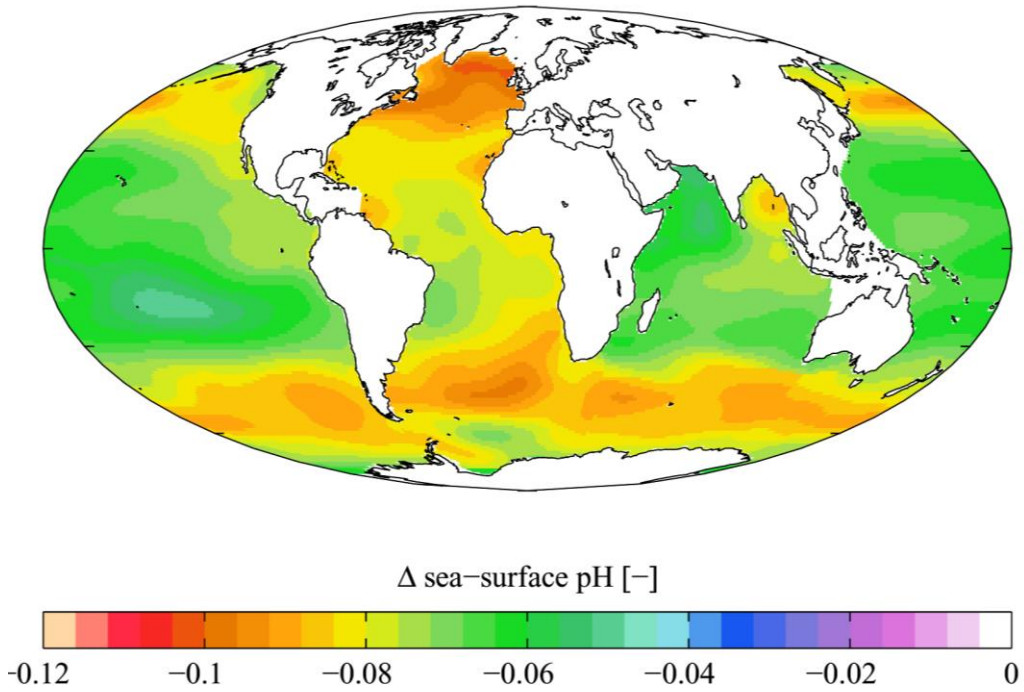
Species sensitivity depends on local conditions (adaptation)

Biological sensitivity



Species sensitivity depends on other environmental conditions (indirect effects, ecology, evolution, other drivers)

Where to monitor to see biological changes?



Chemical rate of change depends on where you are

Factors modulating biological rate of change

- ✓ Biological sensitivity ↑
- ✓ Chemical rate of change ↑

→ Rate of change ↑

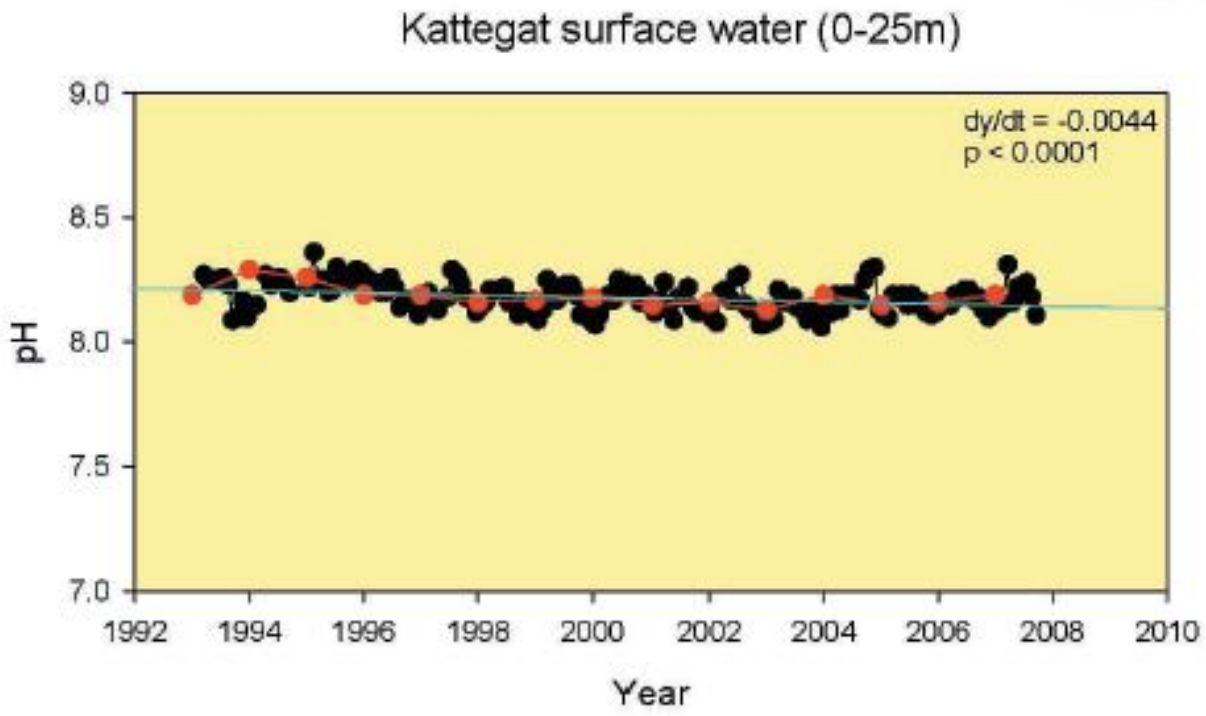
→ Shorter you need to monitor to see an effect and collect robust data

How to estimate how long to monitor to see (robust) changes?

Use experimental data

Example: Gullmarsfjord, Sweden

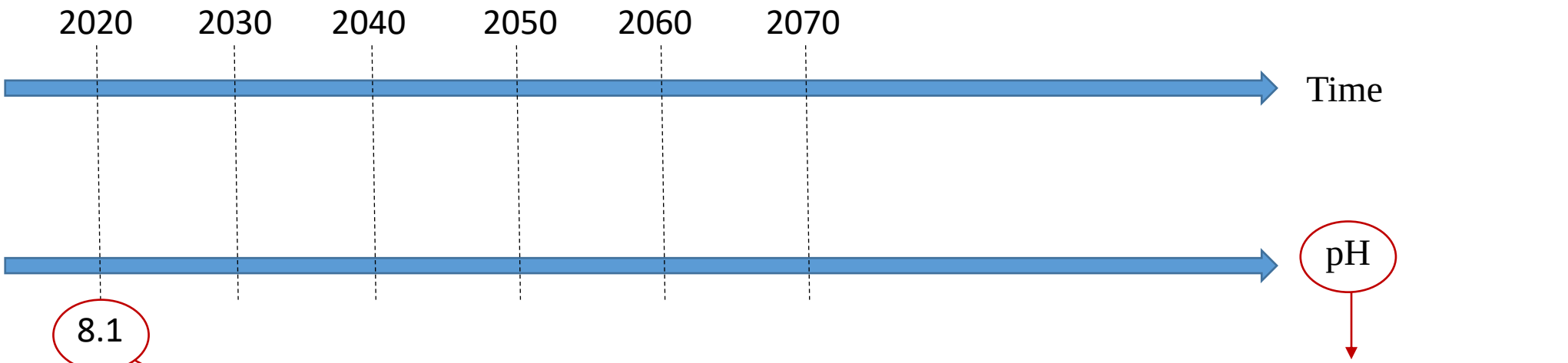
Rate of chemical change



-0.0044 pH unit / year

Combine these data

Step 1: turn time into pH

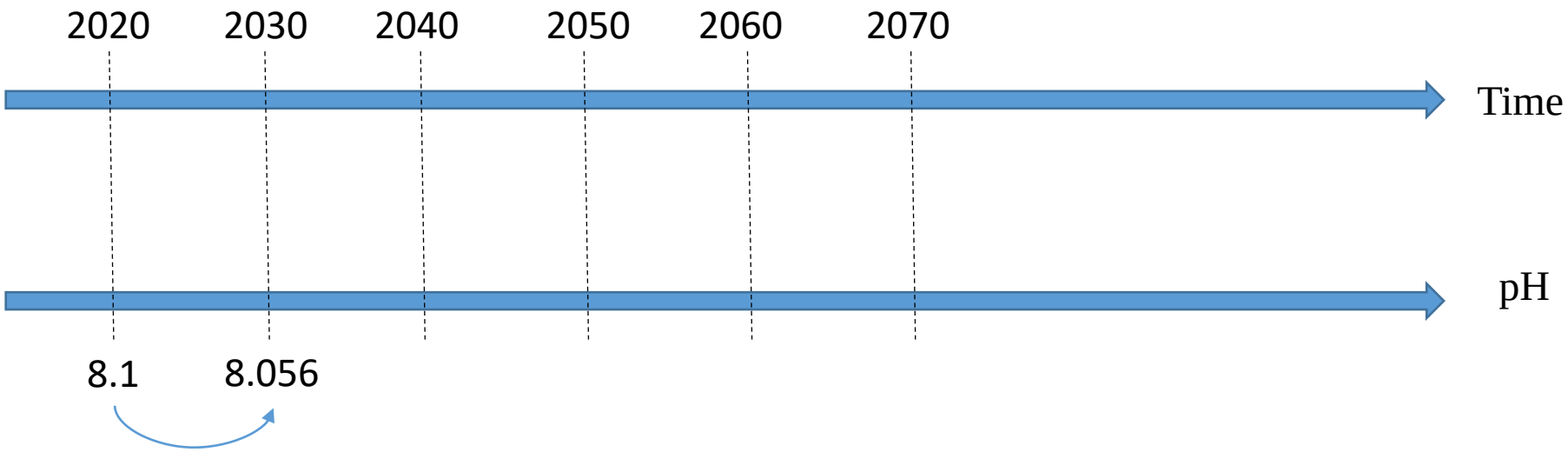


- Present pH (observed)
- Average/extreme/etc. depends on what is biologically relevant

Or any biologically relevant parameter of the carbonate chemistry

Combine these data

Step 1: turn time into pH



$pH_{2030} = pH_{2020}$ + Rate of chemical change x (2030 – 2020)

Rate of chemical change = -0.0044 pH unit / year

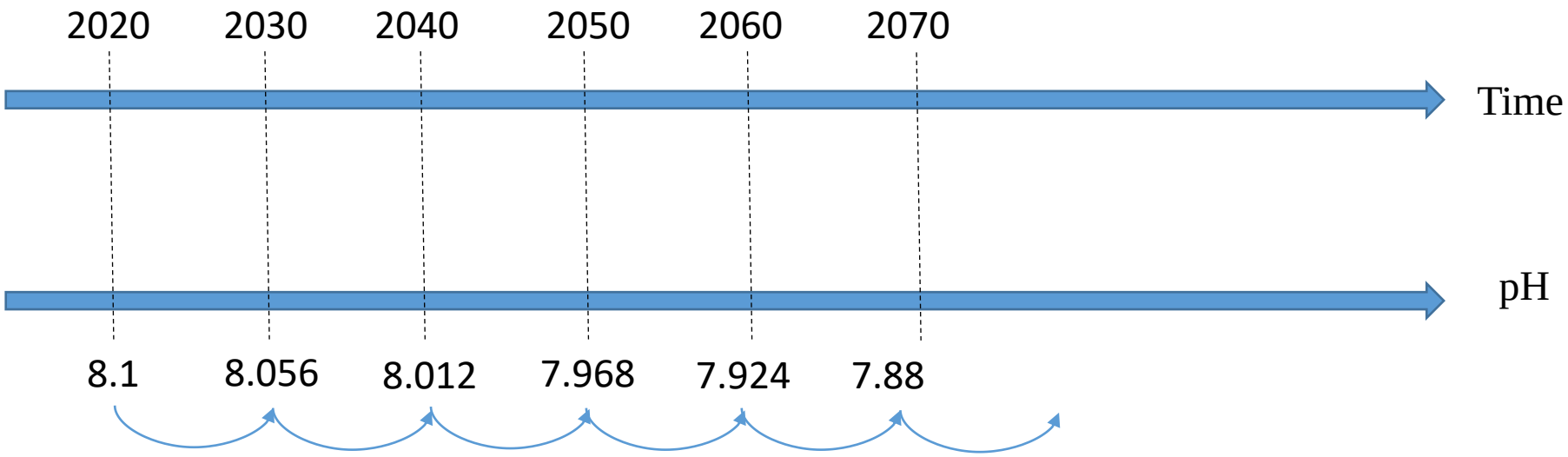
pH_{2030} = 8.1 – 0.0044 x 10 = **8.056**

Limitations:

- Rate not constant (mitigation, modulating factors)

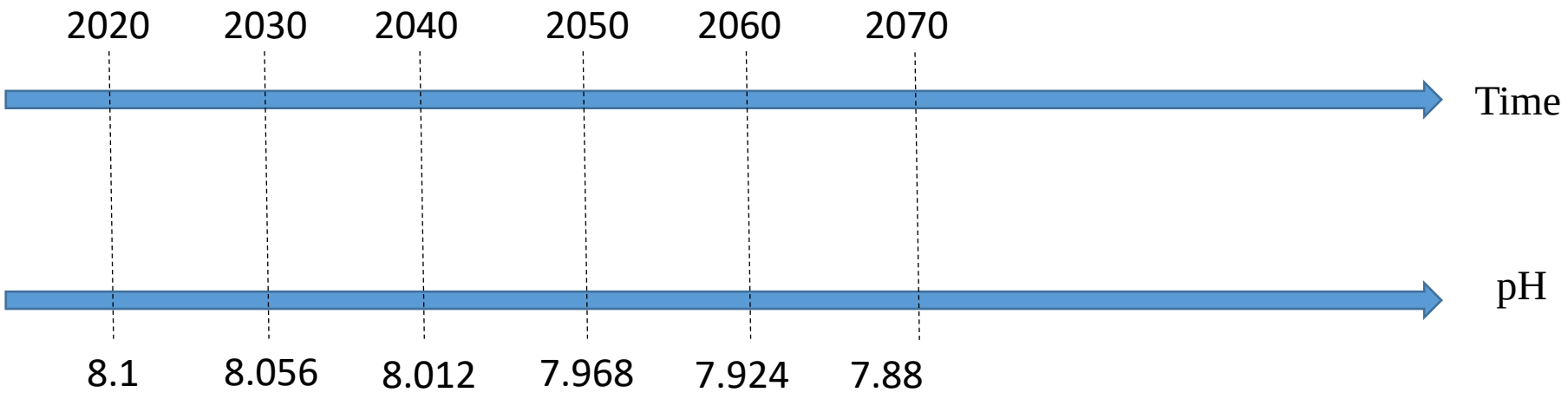
Combine these data

Step 1: turn time into pH



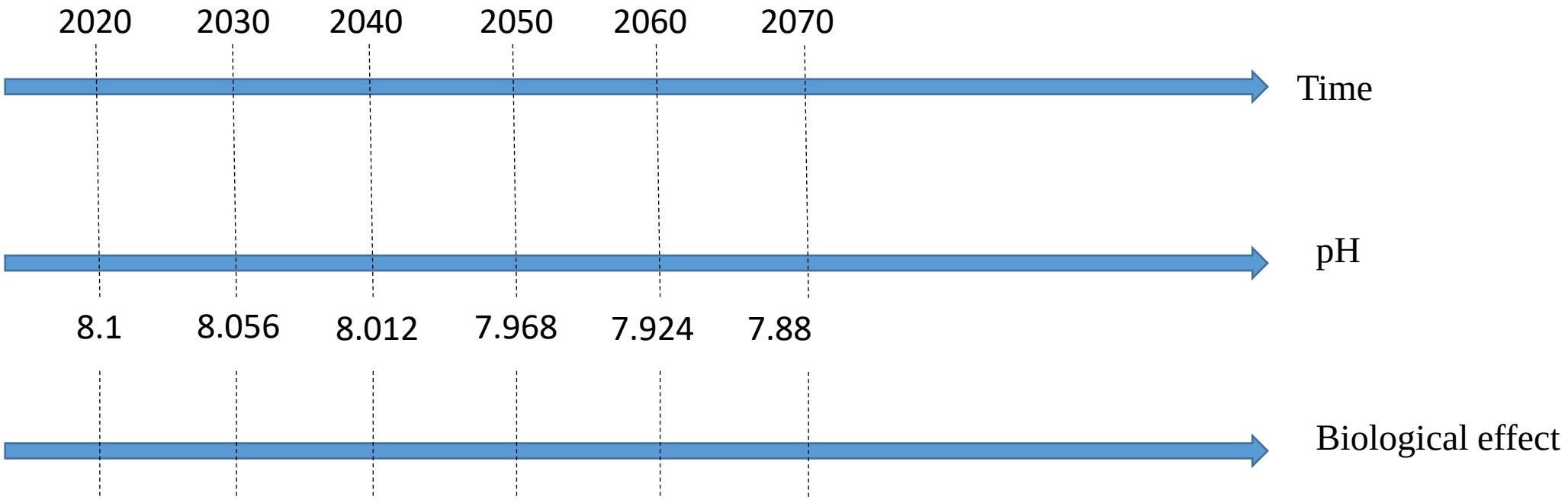
Combine these data

Step 2: turn pH into biological effects



Combine these data

Step 2: turn pH into biological effects



Biological sensitivity (e.g. blue mussels)

www.nature.com/scientificreports

SCIENTIFIC REPORTS

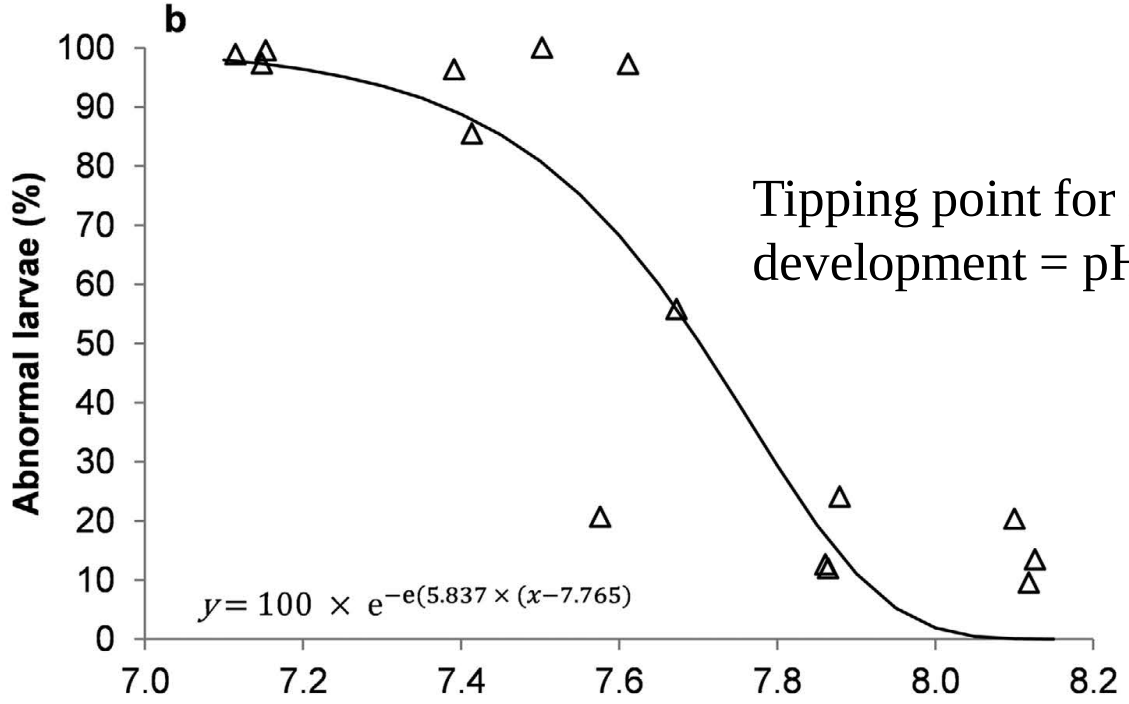
OPEN

Maintained larval growth in mussel larvae exposed to acidified under-saturated seawater

Received: 30 May 2015
Accepted: 03 March 2016
Published: 29 March 2016

Alexander Ventura, Sabrina Schulz & Sam Dupont

Ocean acidification (OA) is known to affect bivalve early life-stages. We tested responses of blue mussel larvae to a wide range of pH in order to identify their tolerance threshold. Our results confirmed that decreasing seawater pH and decreasing saturation state increases larval mortality rate and the percentage of abnormally developing larvae. Virtually no larvae reared at average pH_T 7.16 were able to feed or reach the D-shell stage and their development appeared to be arrested at the trochophore



Tipping point for normal development = pH_T 7.765.

Effect size (in this case, same thing)

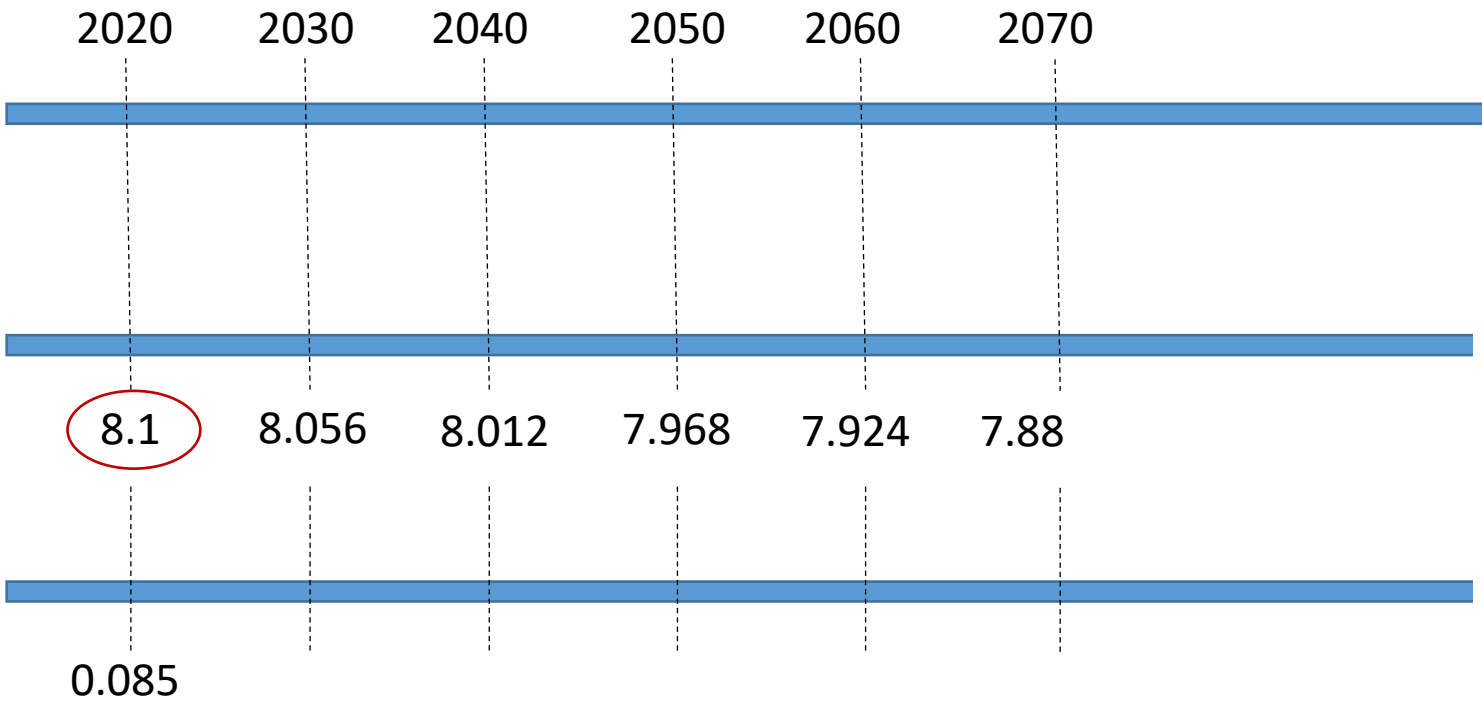
Effect size (%) = 100 x e $^{-e\ (5.837\ x\ (pH\ -\ 7.765))}$

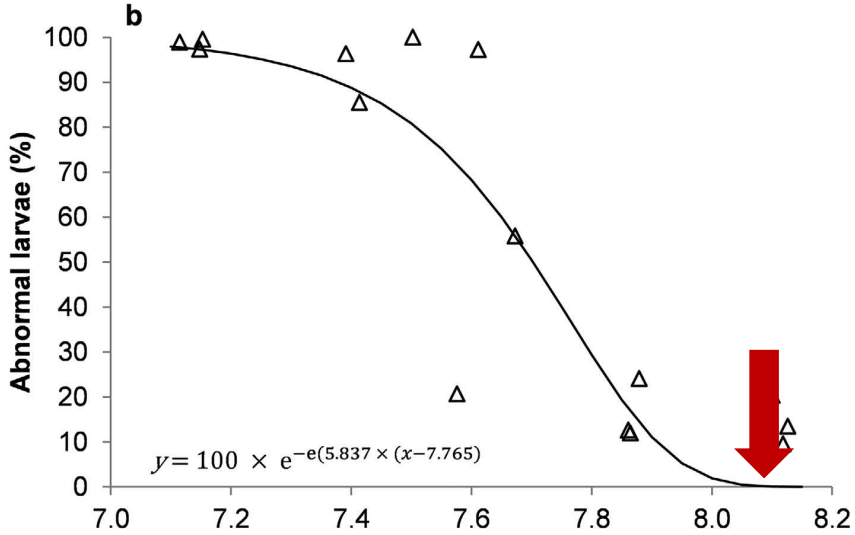
Limitations:

- Experimental design
- Adaptation / Acclimation
- Ecological interactions
- Modulating factors
- Etc.

Combine these data

Step 2: turn pH into biological effects

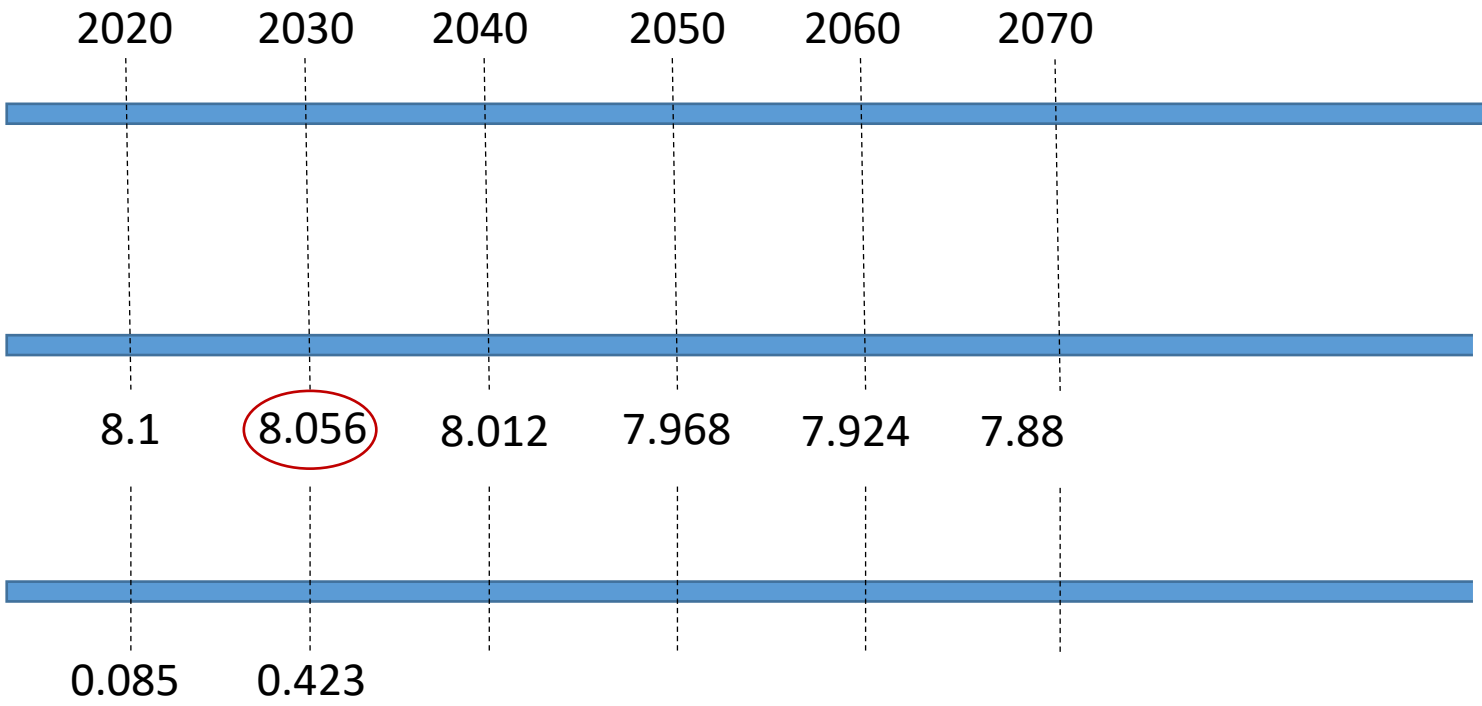


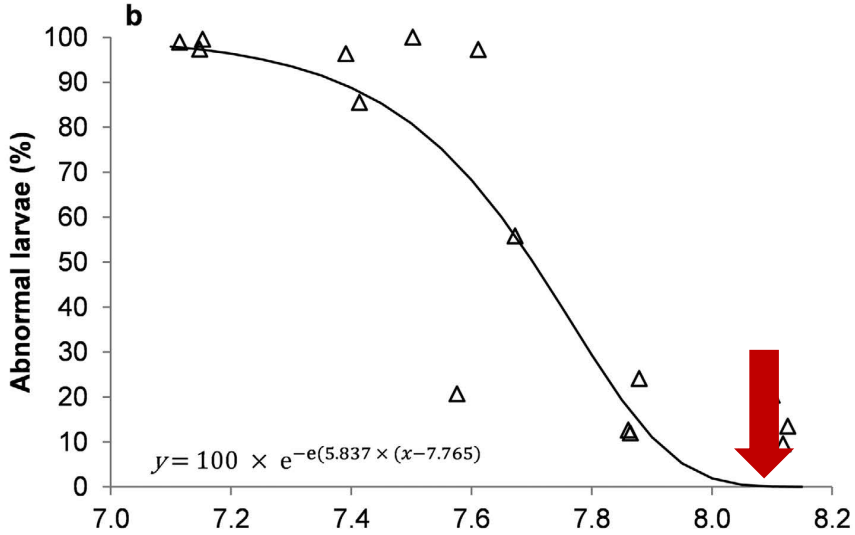


$0.085303513 = 100 \times e^{-e\,(5.837 \times (8.056 - 7.765))}$

Combine these data

Step 2: turn pH into biological effects

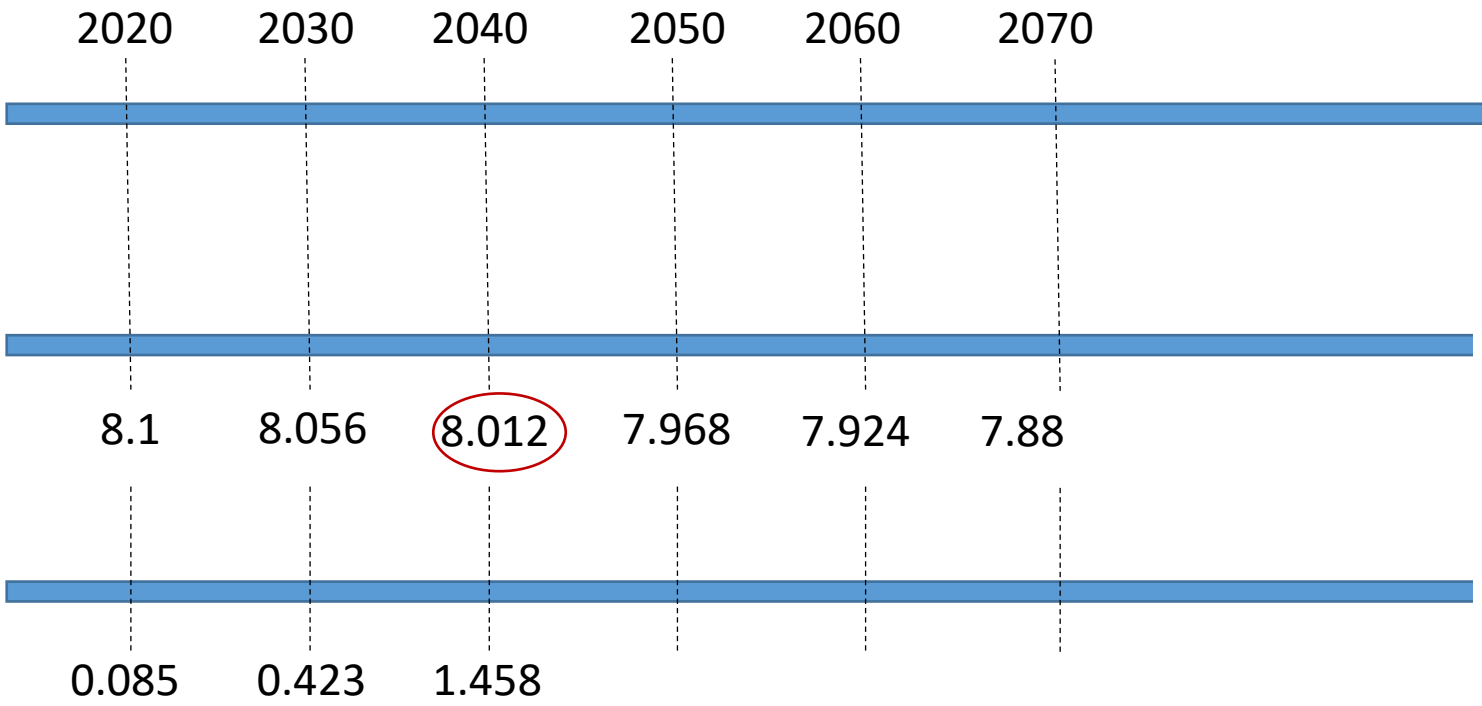


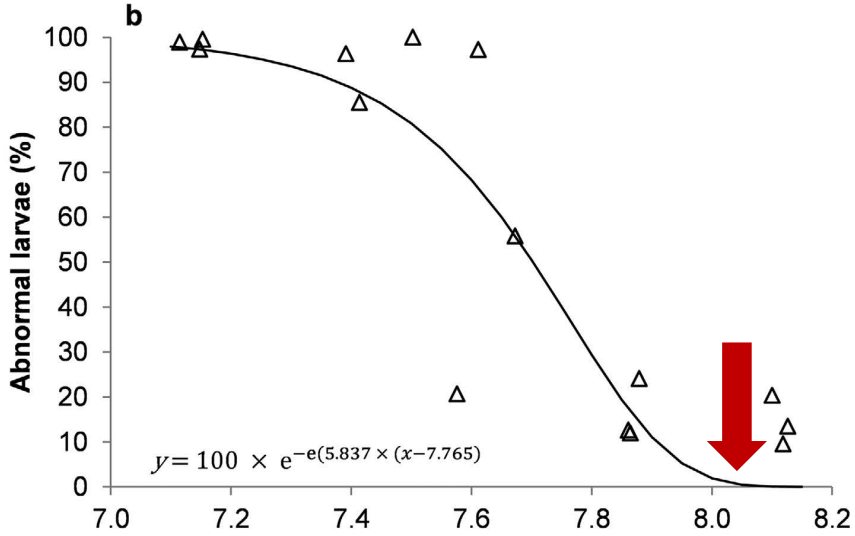


$$0.422765065 = 100 \times e^{-e\,(5.837 \times (8.056 - 7.765))}$$

Combine these data

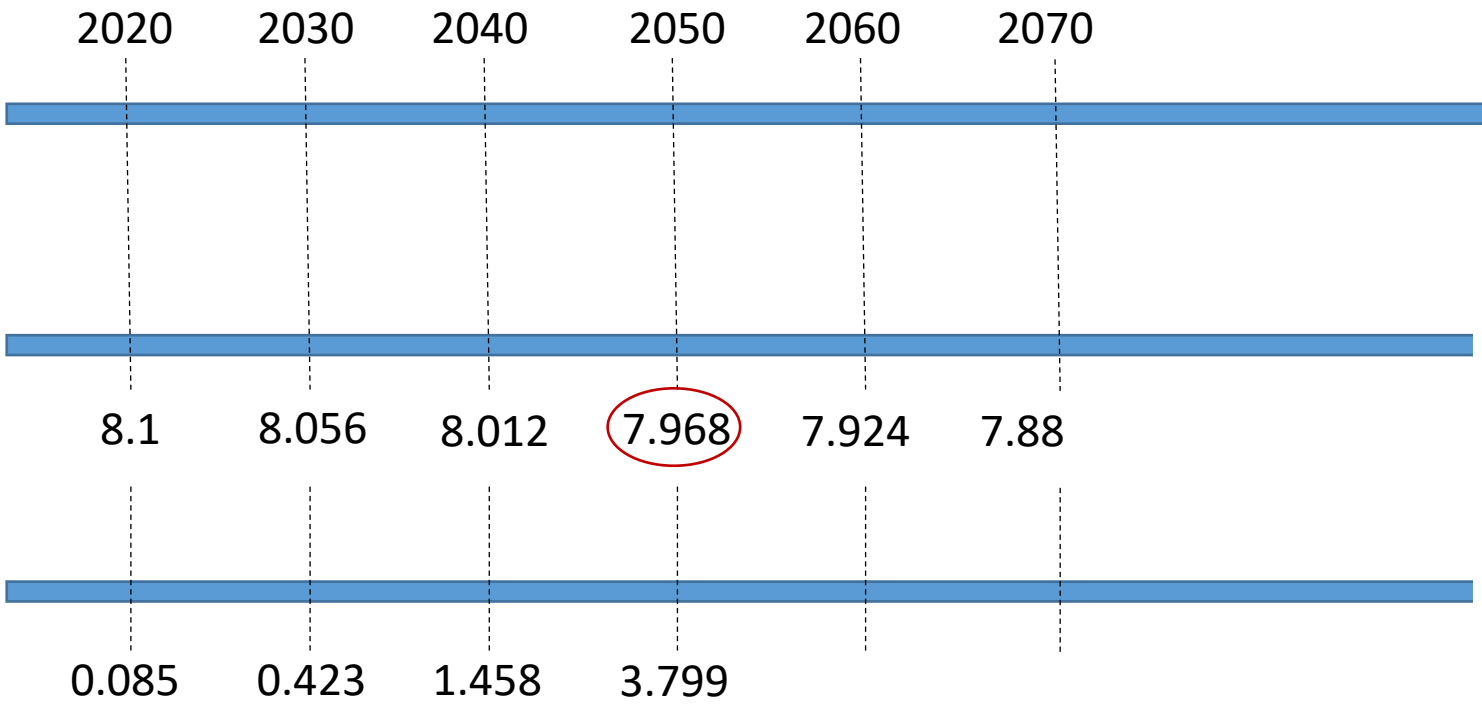
Step 2: turn pH into biological effects

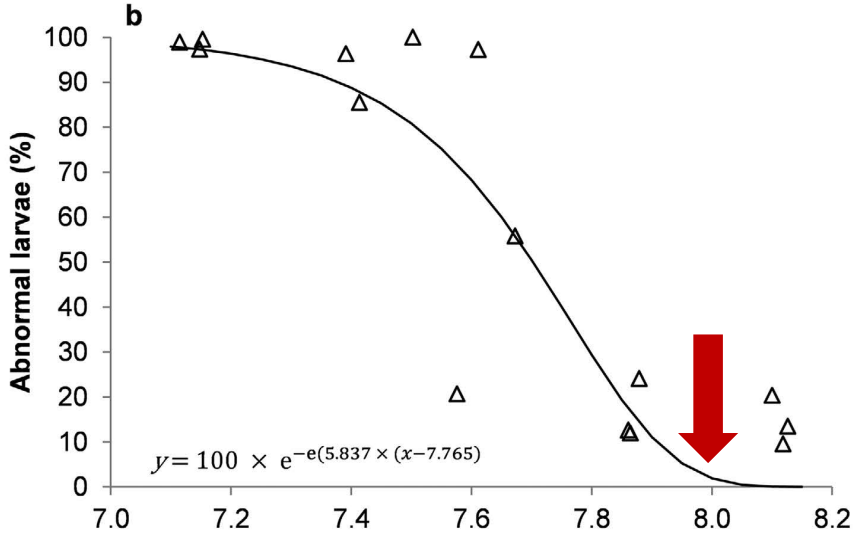




Combine these data

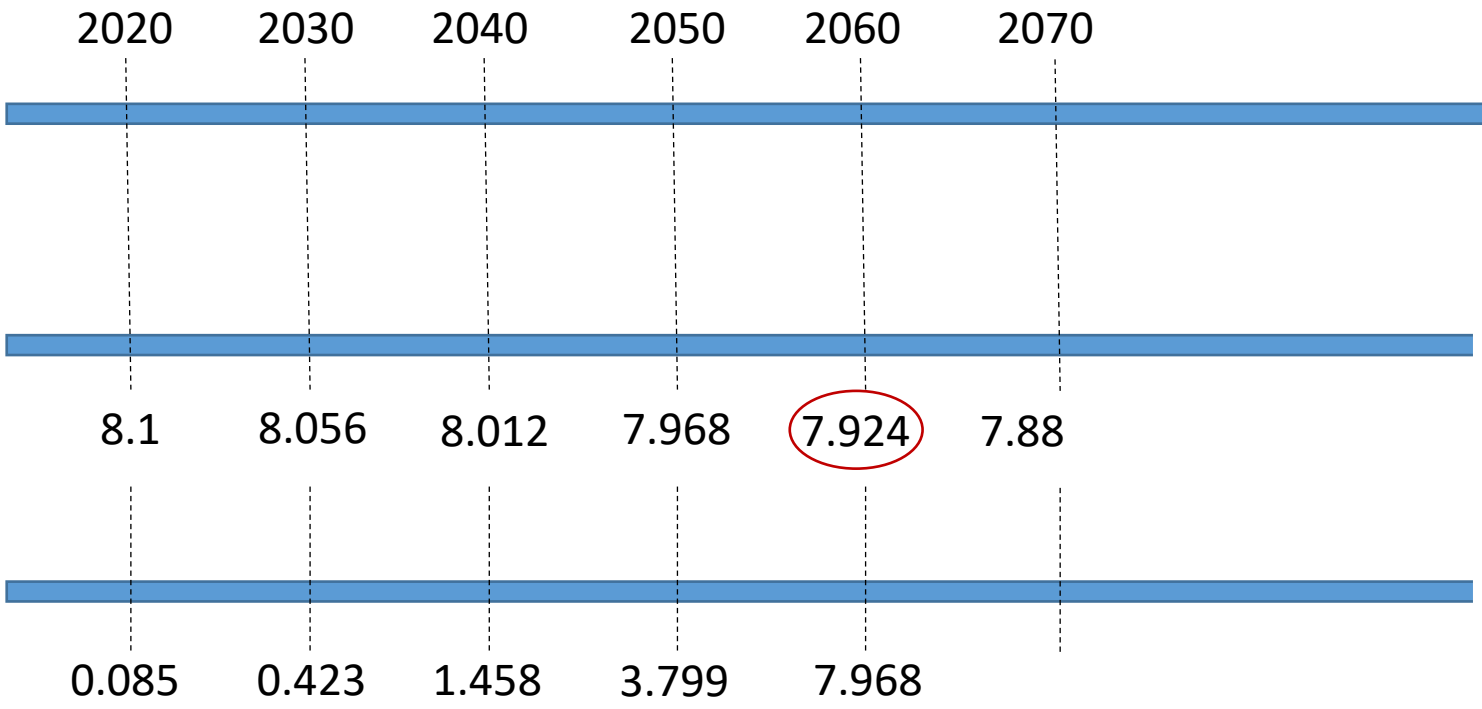
Step 2: turn pH into biological effects

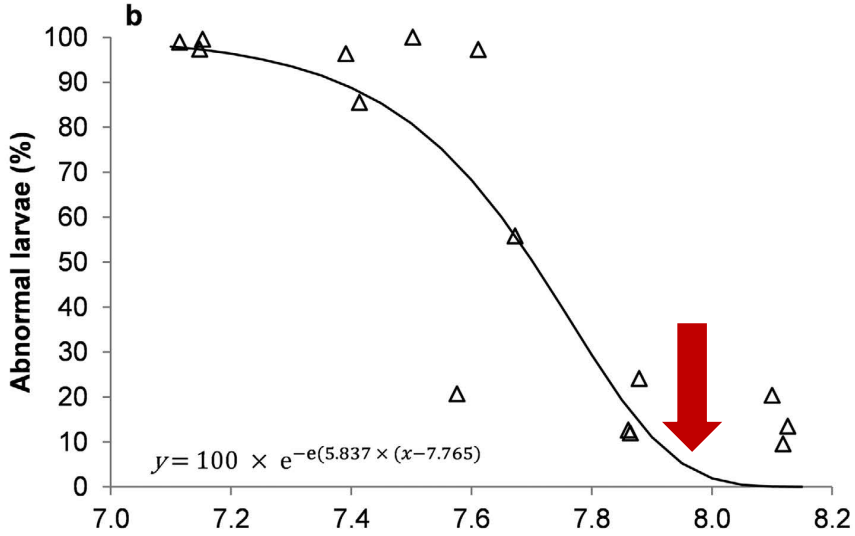




Combine these data

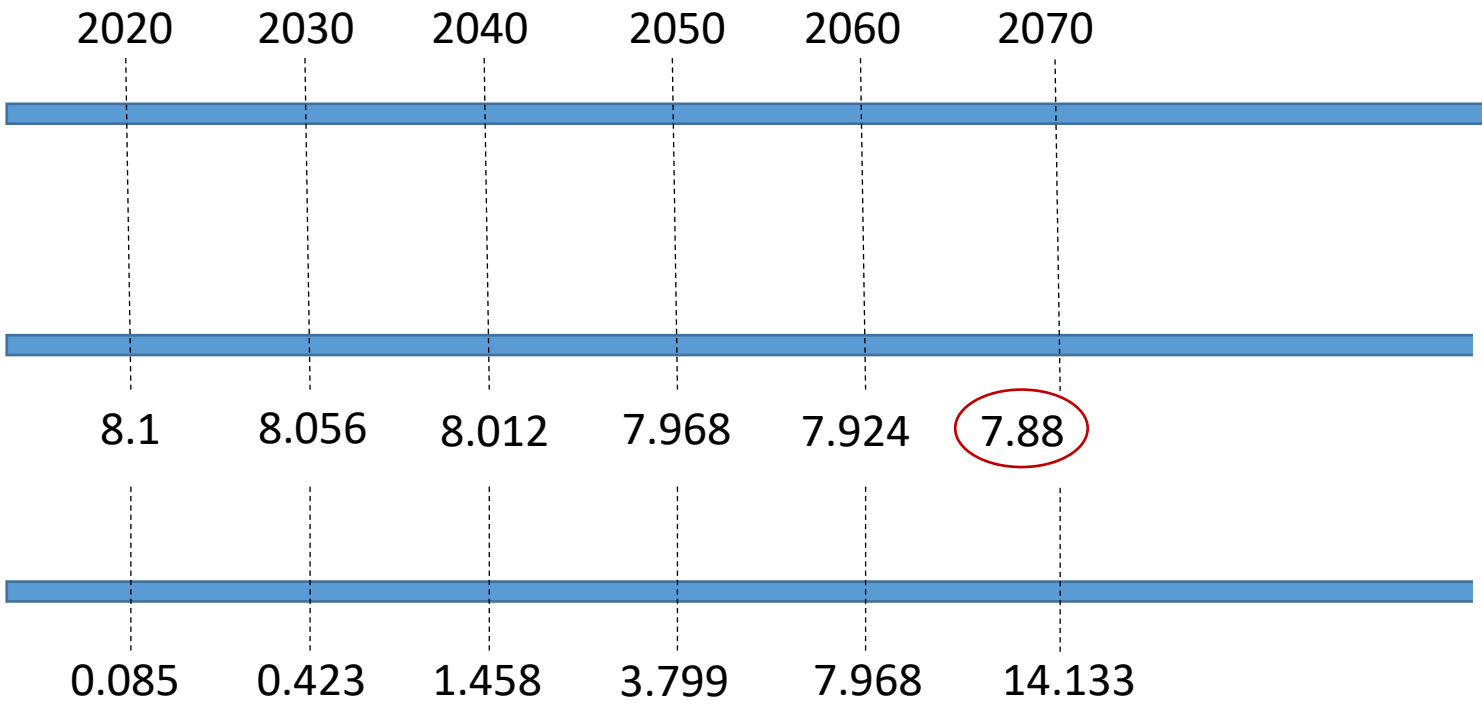
Step 2: turn pH into biological effects

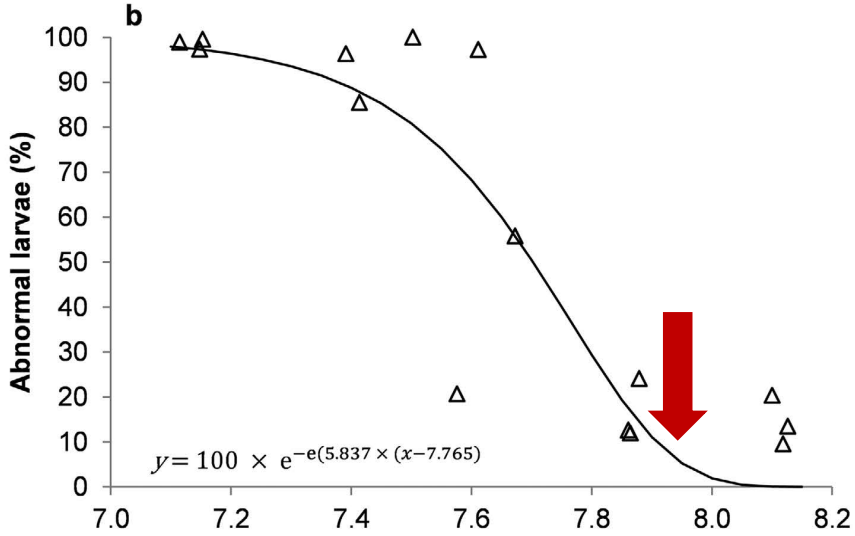




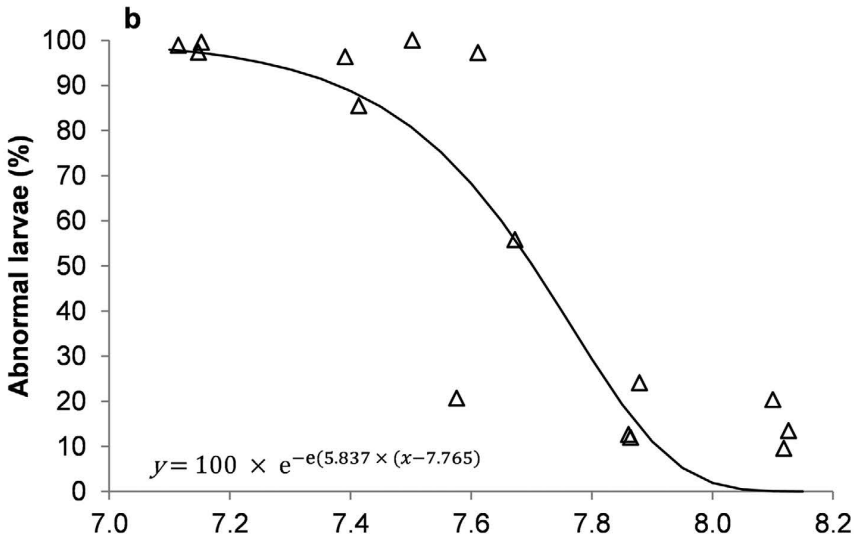
Combine these data

Step 2: turn pH into biological effects



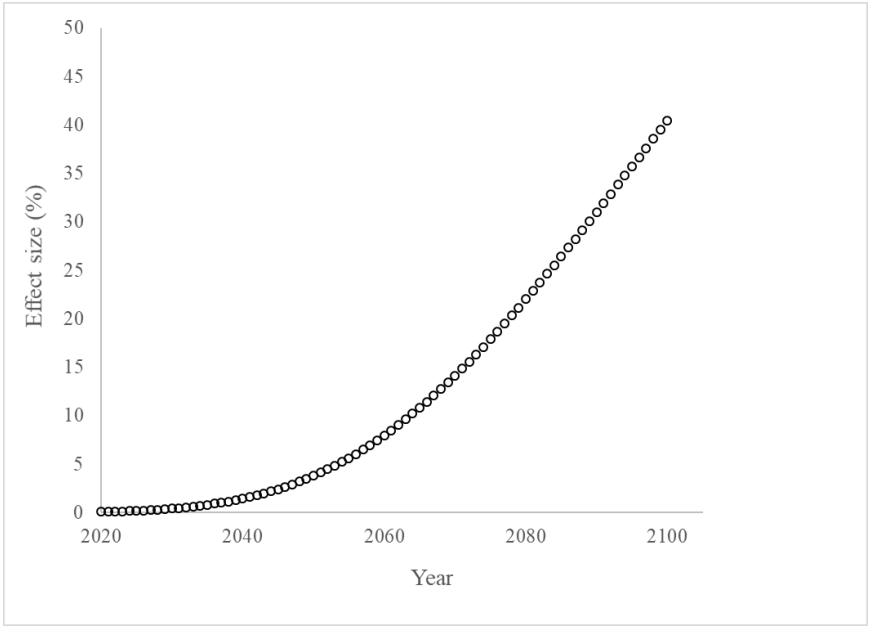


What can be expected



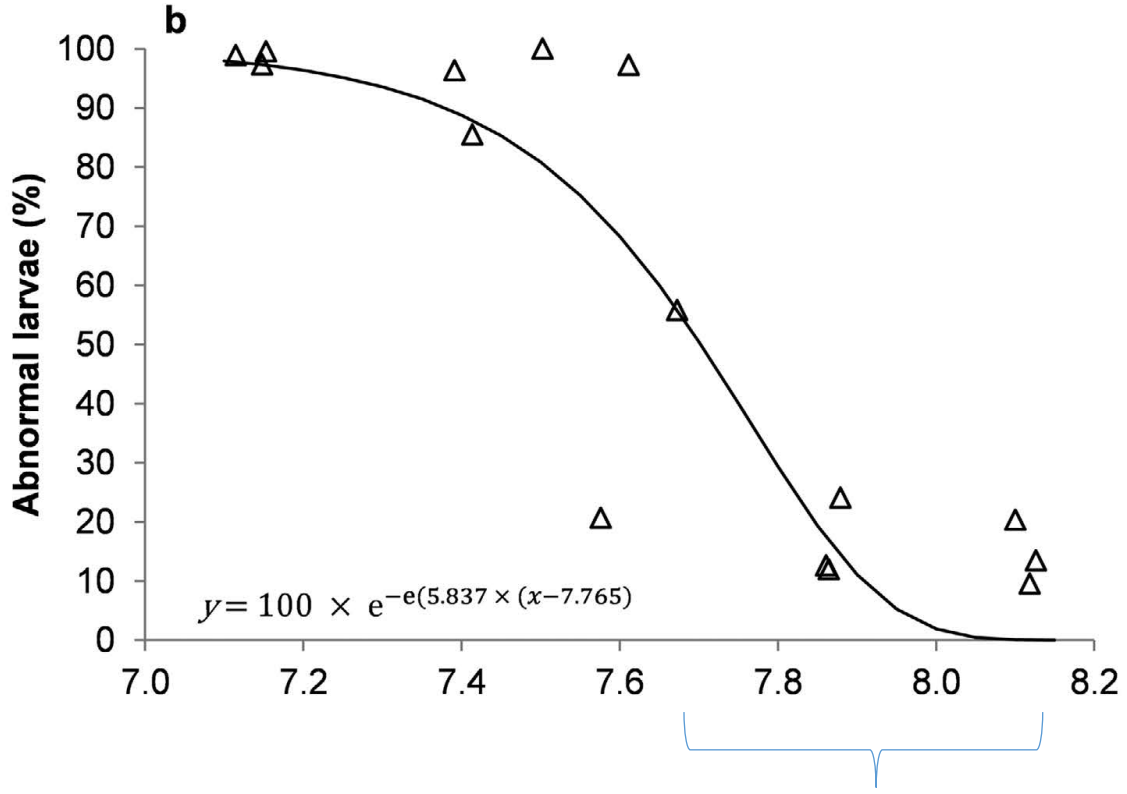
Biological response

Chemical rate of change



Biological observation (projected)

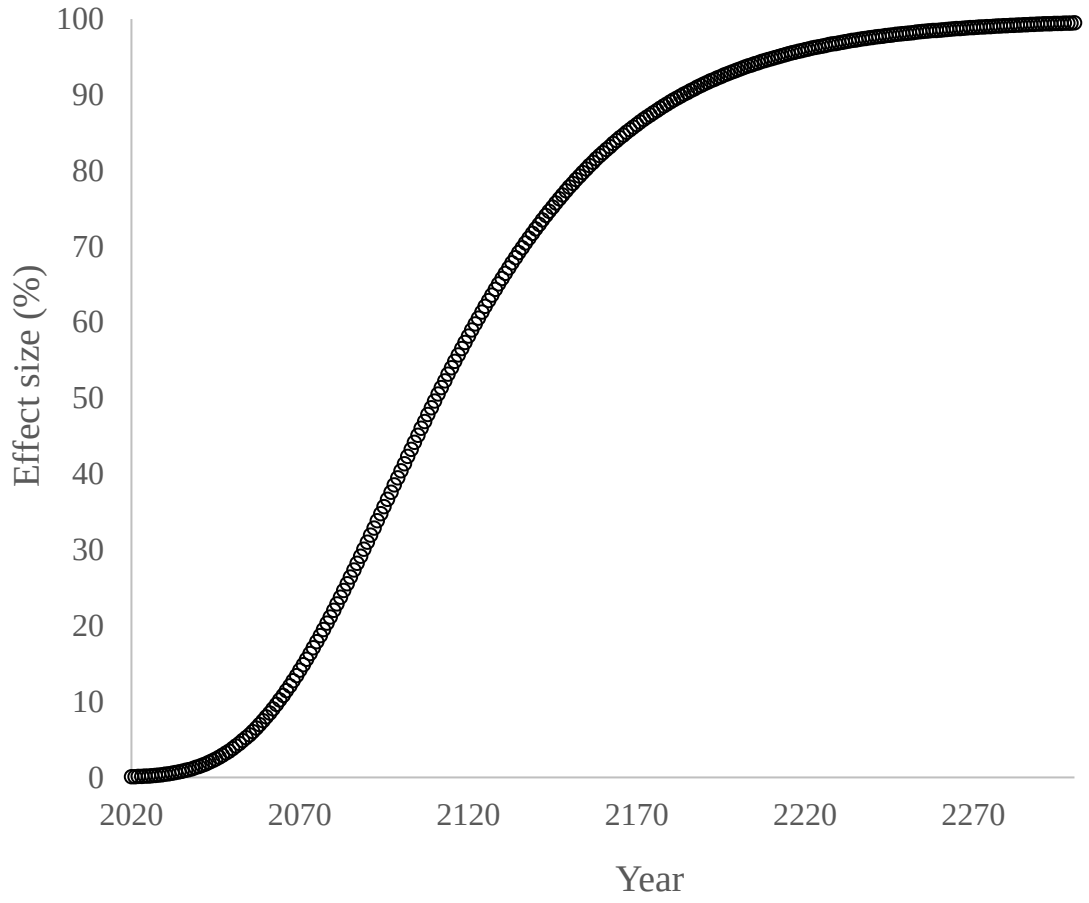
Step 3: estimate the rate of biological change



Range covered by 2100

- Not linear
- Need a wide range of pH to have the full curve

Step 3: estimate the rate of biological change

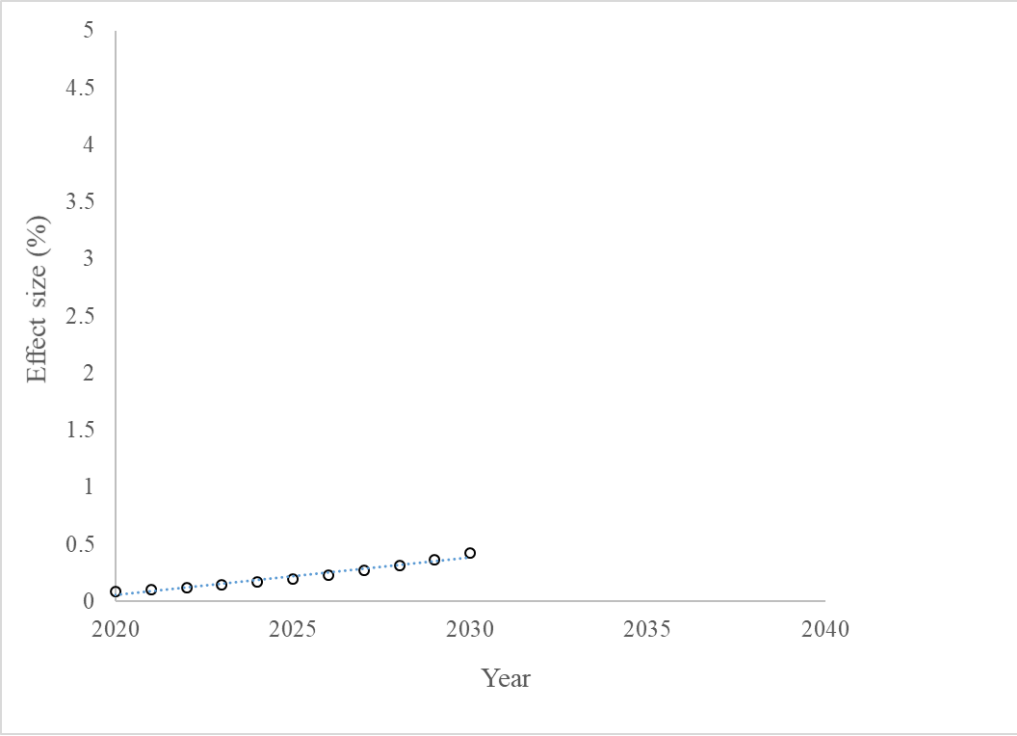


Not possible to calculate real non-linear rate of change with incomplete dataset

In that example, need 200 years of data

Step 3: estimate the rate of biological change

10 years of data



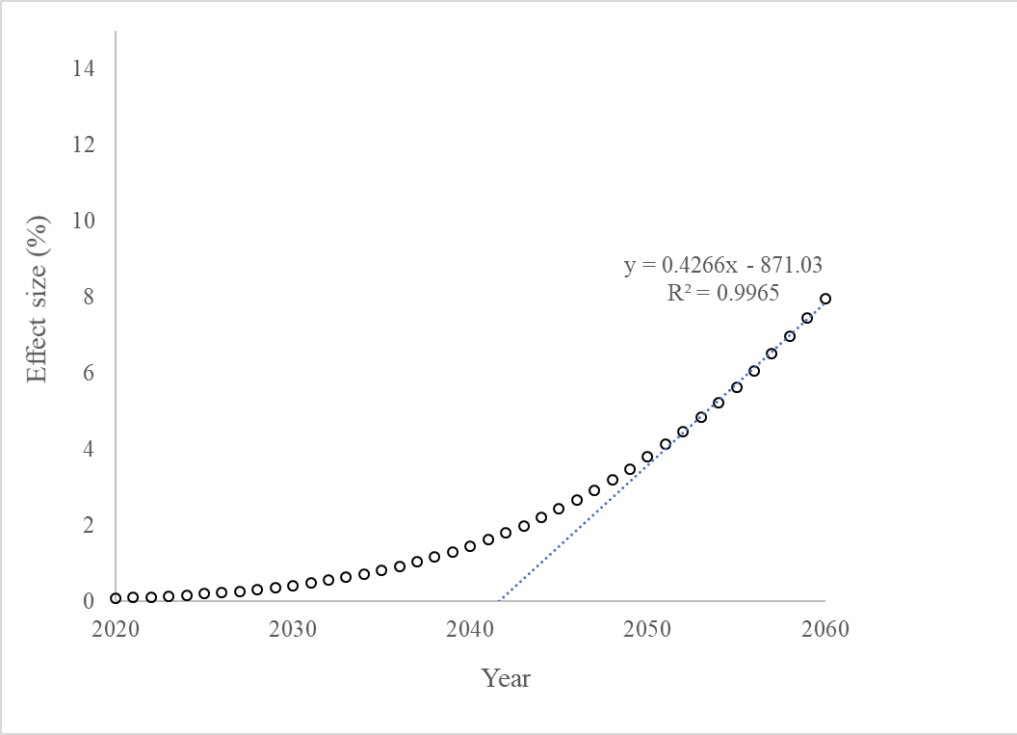
Linear regression (R^2=0.97)

Effect size = 0.0332 x Time – 67.043

Biological rate: 0.033 % / year

Step 3: estimate the rate of biological change

40 years of data



Linear regression (R^2=0.99)

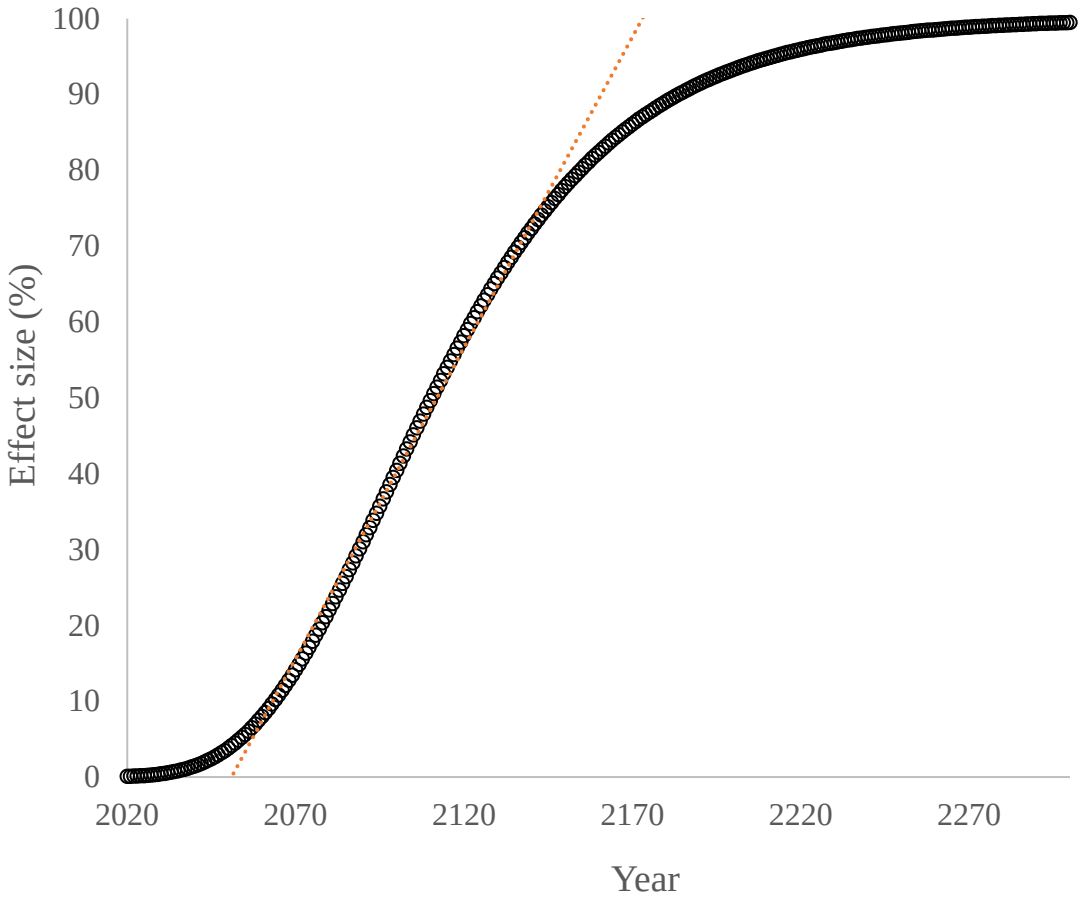
Effect size = 0.4266 x Time – 871.03

Biological rate: 0.427 % / year

”Maximum” linear growth

Step 3: estimate the rate of biological change

All curve

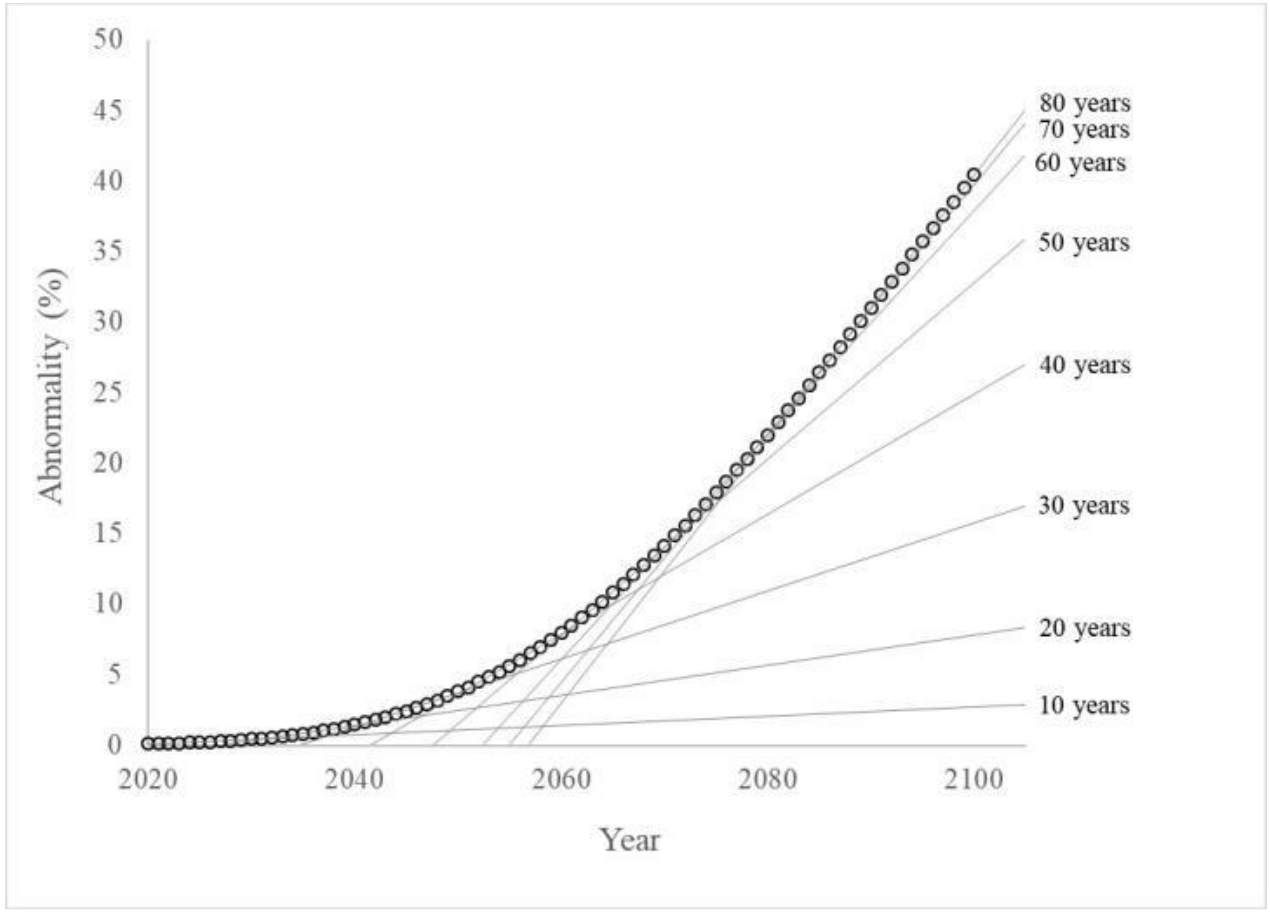


Linear regression (R^2=0.99)

Effect size = 0.9196 x Time – 1681

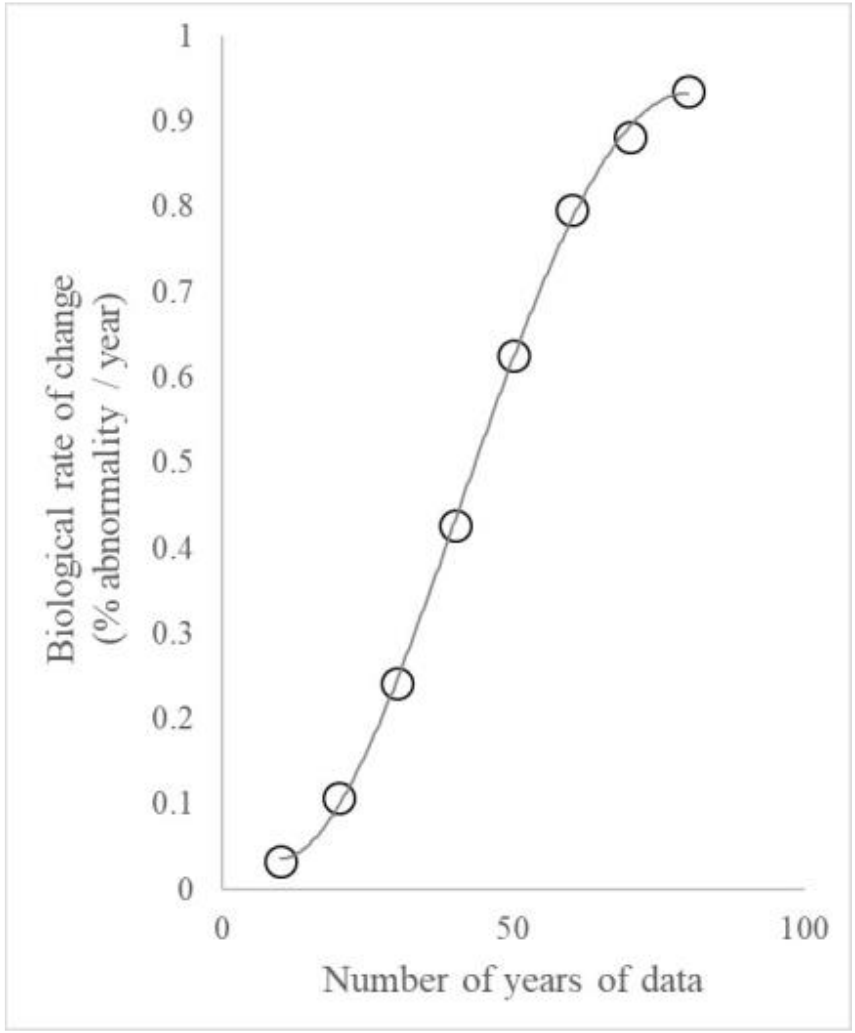
Max biological rate: 0.9196 % / year (linear)

Step 3: estimate the rate of biological change



Estimate the observed maximum rate of change after different duration of biological monitoring

Rate of biological change vs duration of monitoring

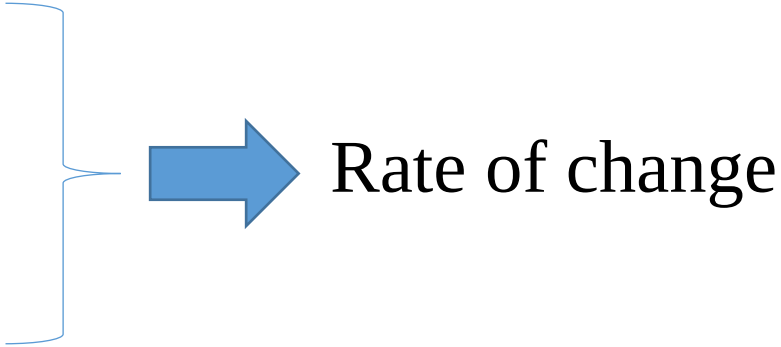


Reach saturation

Need >80 years of data for a robust evaluation

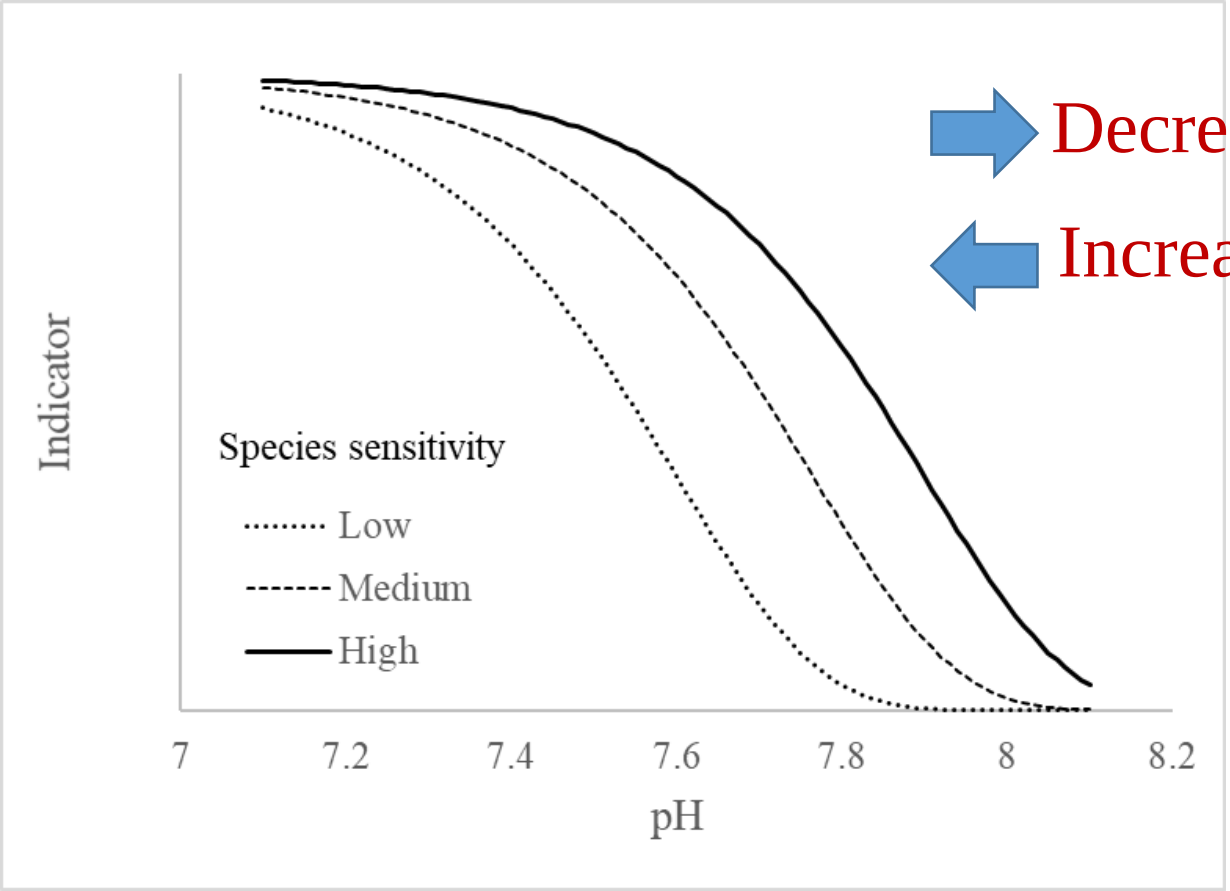
Caution: Factors modulating biological rate of change

- ✓ Biological sensitivity
- ✓ Chemical rate of change



For this exercise we assumed that both were **constants** BUT both can vary over time

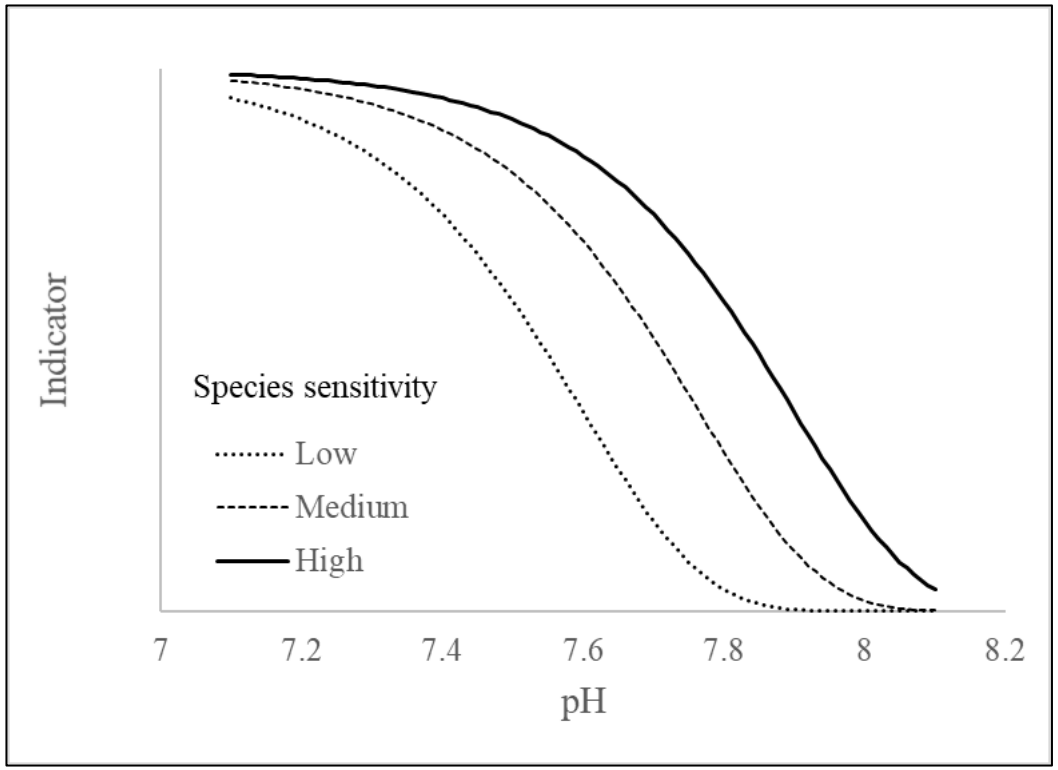
Biological sensitivity

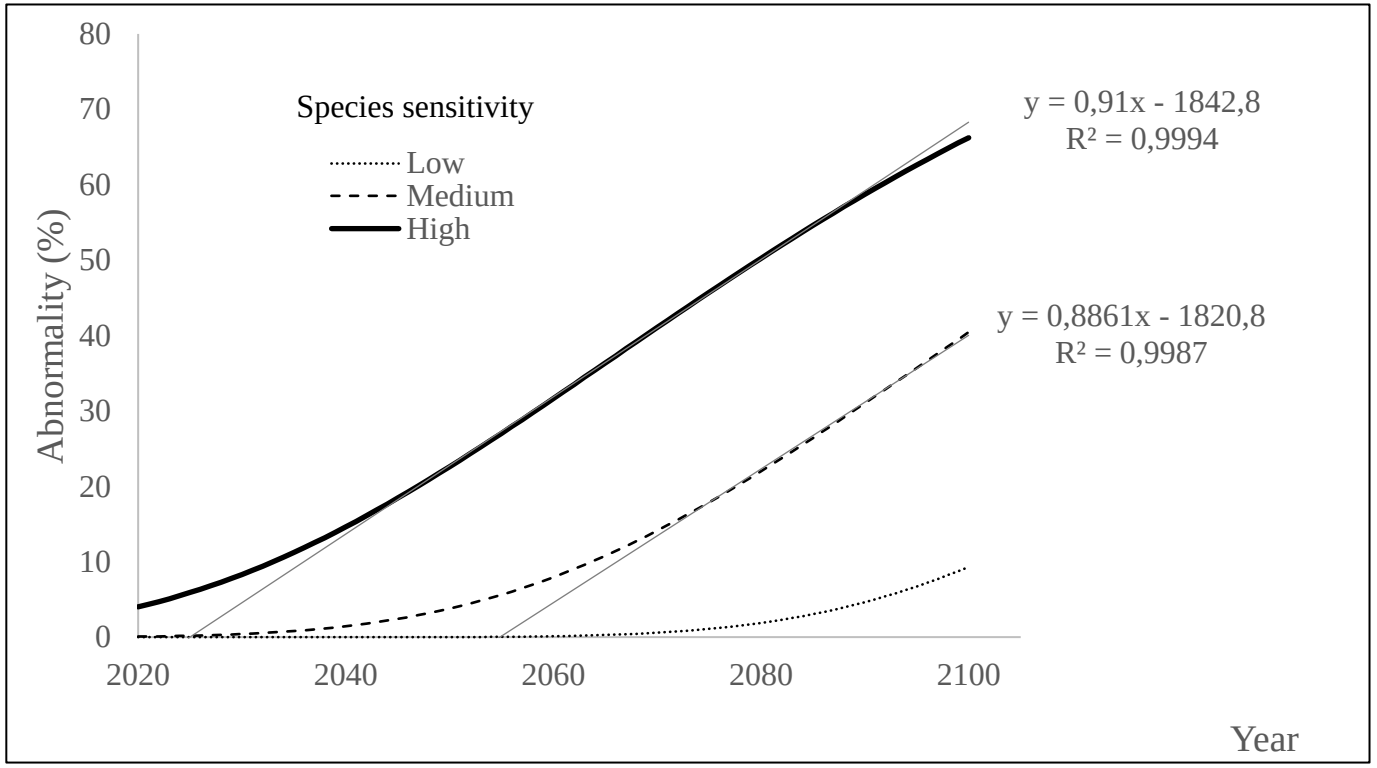


Decreased sensitivity (e.g. Adaptation)

Increased sensitivity (e.g. multiple stressors)

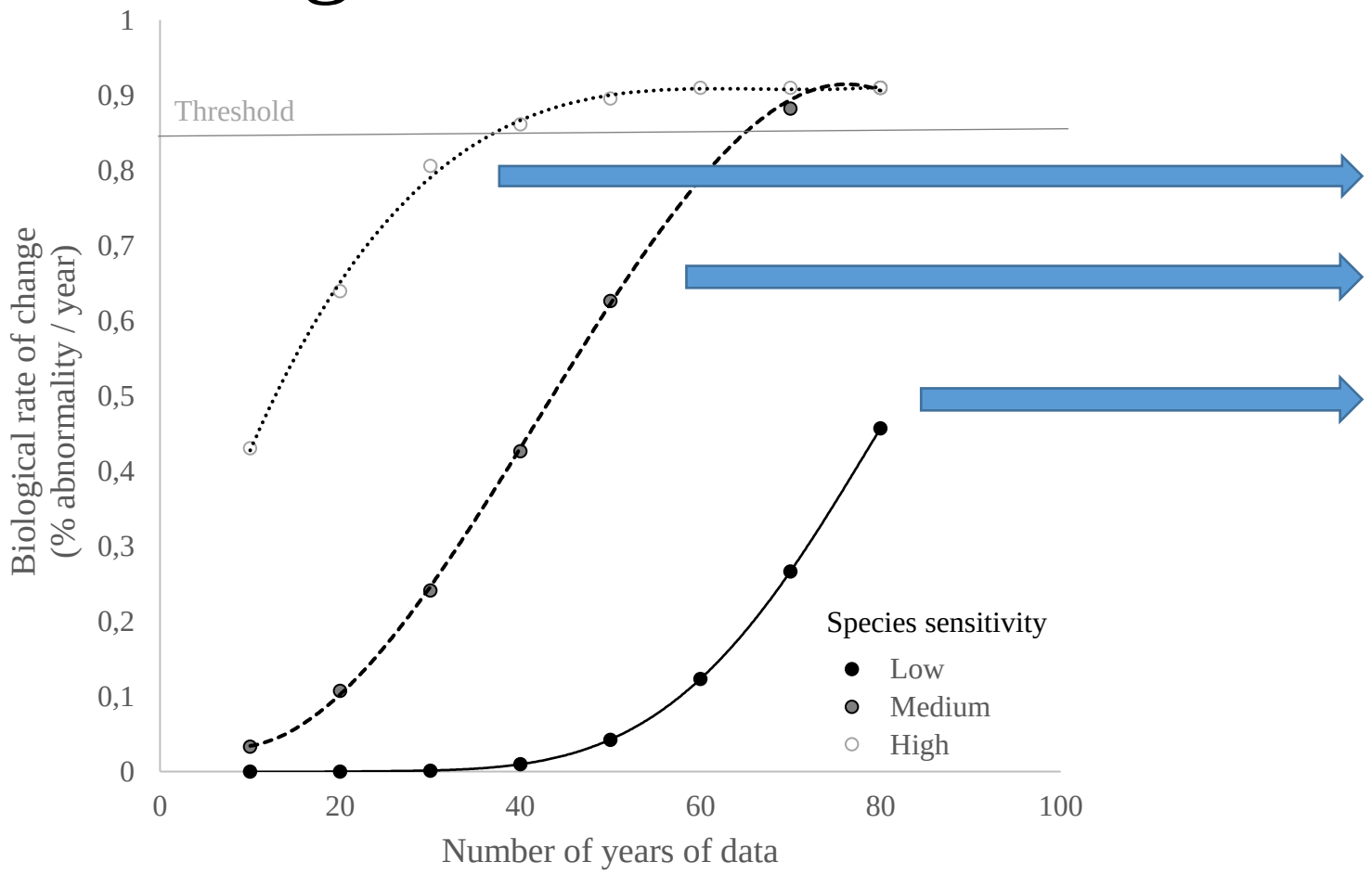
Higher the sensitivity = shorter the monitoring





The higher the species sensitivity, the faster you observe a robust rate of change

Higher the sensitivity = shorter the monitoring



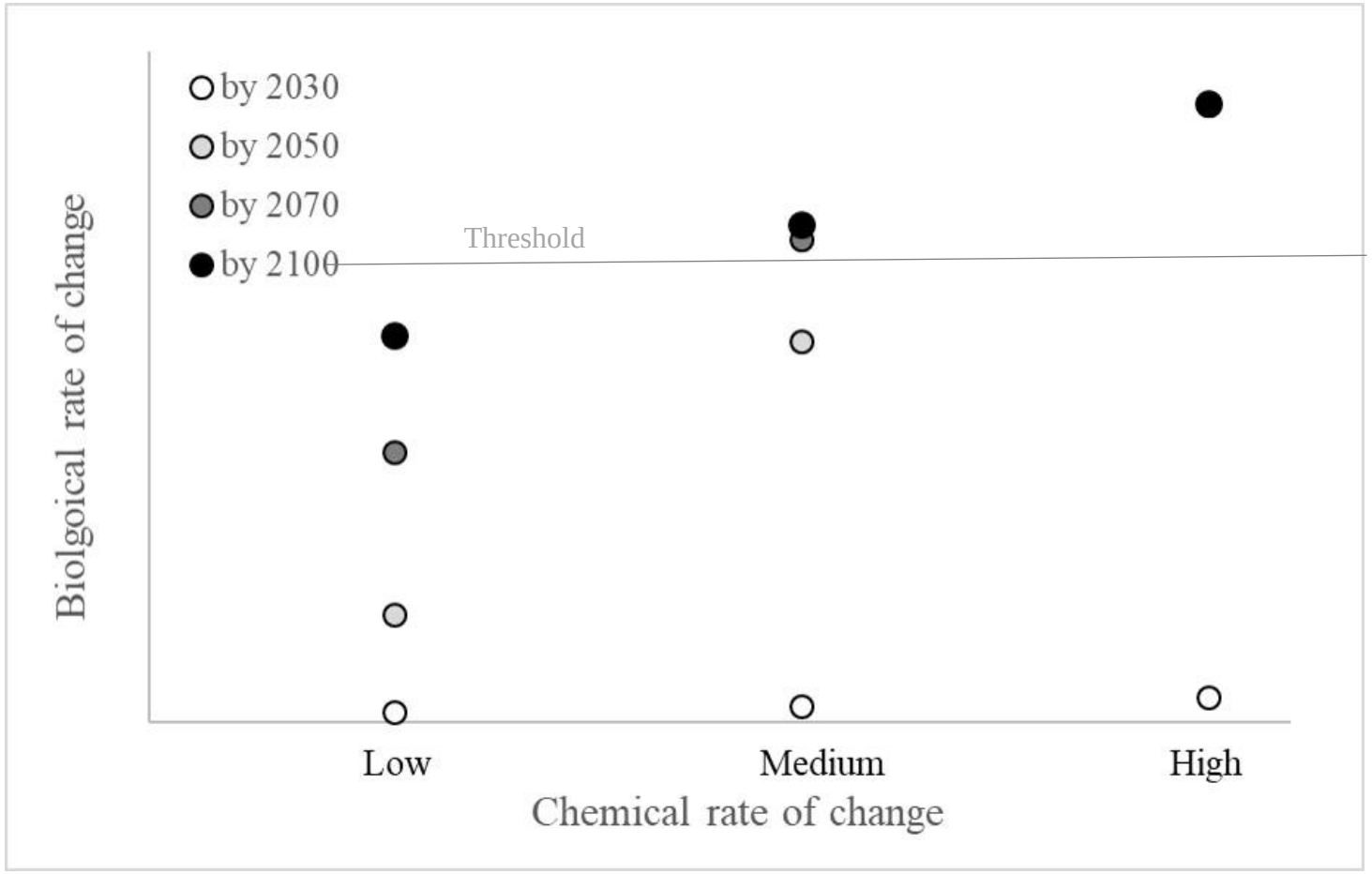
Robust data after:

40y

80y

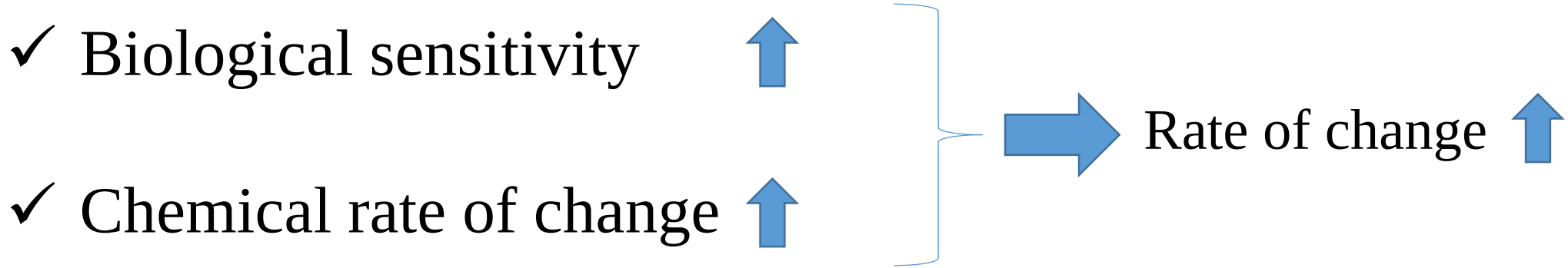
?

Faster the chemical rate = shorter the monitoring



Date to reach robust data: 2100 2070 2050

Summary



IF the goal is to observe robust estimate of biological rate of change, prioritize locations with high biological sensitivity and high chemical rate of change

- ✓ Biological monitoring is valuable in itself
- ✓ We are not here to tell you what to do !
- ✓ There are many reasons to select a site (important, co-location with chemistry, existing infrastructure, etc.)
- ✓ OK to NOT see any change (if robust data)
- ✓ This sub-module is about how to optimize your chances to see OA driven biological changes over a reasonable amount of time

What specific Biological Indicators to measure?

- Insisting that everyone measures the same small sub-set of biological parameters is counter-productive.
- It restricts the scope of research, inhibits new discoveries and is not inclusive to all, in terms of either geography, local scientific interests or research capability.
- In the natural world it is unlikely that biological changes will be solely driven by OA so no biological measure is a perfect indicator of OA impact.

- Our approach would be to allow researchers to chose from a wide variety of parameters and methods, provided the chosen methodologies are robust and the data collected contribute to 1 of 5 overarching OA impact themes.
- Our 5 proposed impact themes focus on key biological processes for which we have some mechanistic understanding to suggest they are potentially sensitive to changes in carbonate chemistry.

Calcifying Organisms and Calcification

Rationale:

- Calcium carbonate ($CaCO_3$) structures for structural support and protection is used by many marine organisms.
- Changes in seawater chemistry have been shown to strongly affect calcium carbonate structures and biomineralization rates.
- Studies on calcifiers is perhaps the most mature area of OA impact research.

Indicator categories and observations:

- ***Relative prevalence and success of calcifying organisms within an ecosystem***. [Changes in biomass/abundance/percent cover of biocalcifying species, compared to non-calcifying species. Inorganic to organic biomass ratios (PIC:POC) of individual organisms, populations or whole assemblages.]

- ***Calcified Biostructure Morphology.*** [State, structure and mineral composition of calcified biostructures. Calcified structure morphology or function such as weight, density, damage or abnormality, dissolution severity, or strength.]

- ***Rates of Calcification Calcifying.*** [Measured rates of calcification or dissolution on organismal to ecosystem scales.]

Autotrophs and Primary Production (Photosynthesis)

Rationale:

- Primary production serves as the foundation for all marine ecosystems and CO_2 is the fundamental fuel for photosynthesis .
- Yes, temperature and nutrients are very important, but increasing CO_2 can still modulate primary production via interactions with metabolically-costly carbon concentrating mechanisms as well as a broader suite of physiological and biochemical factors, including proton pumps, cellular membrane potential, enzyme activity, and energy partitioning.
- CO_2 and pH can have indirect effects, such as regulating flagellar motion (and thus cell motility and access to nutrients) and the chemical availability of essential micronutrients.

Indicator categories and observations:

- ***Biomass/Standing Stock***. [Total chlorophyll a concentration, phytoplankton cell abundance, microphytobenthos, macroalgae or seagrass biomass]

- ***Productivity Rates.*** [Carbon fixation rates, individual or community growth or production rates.]

- ***Phenology.*** [Onset or duration of blooms or other rapid growth periods.]

Heterotrophs and Secondary Production (Growth and Energetics)

Rationale:

- Long-term exposure to elevated pCO_2 levels increases metabolic energy demand in many marine organisms, to support increased acid-base balance, increased calcification costs, and increased physical activities.
- Additional energy expenditures leave less energy available to invest in other key processes, including protein synthesis and growth.
- For humans, reductions in marine secondary production may have profound implications for fisheries and aquaculture.

Indicator categories and observations:

- ***Biomass / Standing Stock.*** [Changes in total heterotrophic community or individual abundance and biomass, body average size, percent cover.]

- ***Productivity Rates.*** [Rates of individual or community growth or secondary production, from *in-situ* techniques or algorithms.]

- ***Phenology.*** [Onset, appearance or duration of specific life stages (e.g. time spent in plankton, inter-moult times.]

Biodiversity and Community Structure (Mortality)

Rationale:

- Ocean Acidification has been seen to cause mortality in many species.
- Sensitivity of marine organisms varies enormously between species allowing OA to act directly as a strong selective pressure, decreasing biodiversity directly through species loss and altering community structure.
- Or indirectly through altered competition, trophic interactions, decreasing energy generation and flows, degrading critical biogenic habitats, or increasing susceptibility to pathogens and diseases.

Indicator categories and observations:

- ***Taxonomic Diversity / Community Composition.*** [Identity and quantity (number or biomass) of the species/taxa/groups present within a community or assemblage at any given time. Used to calculate a wide variety of indices, each focussing on specific aspects of community structure and biodiversity.]

- ***Functional or Trait Diversity.*** [Requires the collection of species abundance/biomass data as described above, but now the individual organisms are grouped, not by their taxonomic relationships, but by their shared functional, ecological or behavioural traits. The same biodiversity metrics as used for describing taxonomic diversity can then also be applied to these aggregated data to generate estimates of functional or trait diversity.]

Genetic Changes

Rationale:

- Ocean Acidification drives phenotypic and genetic changes (natural selection)
- This can be specific (OA signature)
- Genetic signal dependent on diversity, strength and direction of the pressure

Indicator categories and observations:

- ***Neutral genetic variation.*** [= non-functional genetic variation. Population genetic parameters (e.g. number of alleles, heterozygosity, effective population size, inbreeding and population divergence) using classic molecular markers (e.g., allozymes, microsatellites or mtDNA) or through high-throughput sequencing approaches.]

- ***Functional genetic variation.*** [= functional genetic variation. Using quantitative trait locus (QTL), genome-wide association studies (GWAS), genome scan via restriction-site-associated DNA taqs (RAD-seq), and RNA sequencing (RNA-seq).]

- ***Mutation rates.*** [for few loci (including genes of particular interest) or from whole-genomes using high-throughput sequencing technologies.]