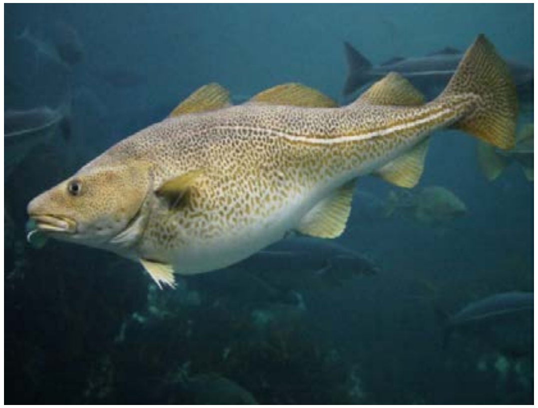
Designing studies to detect the ecological impacts of offshore wind development

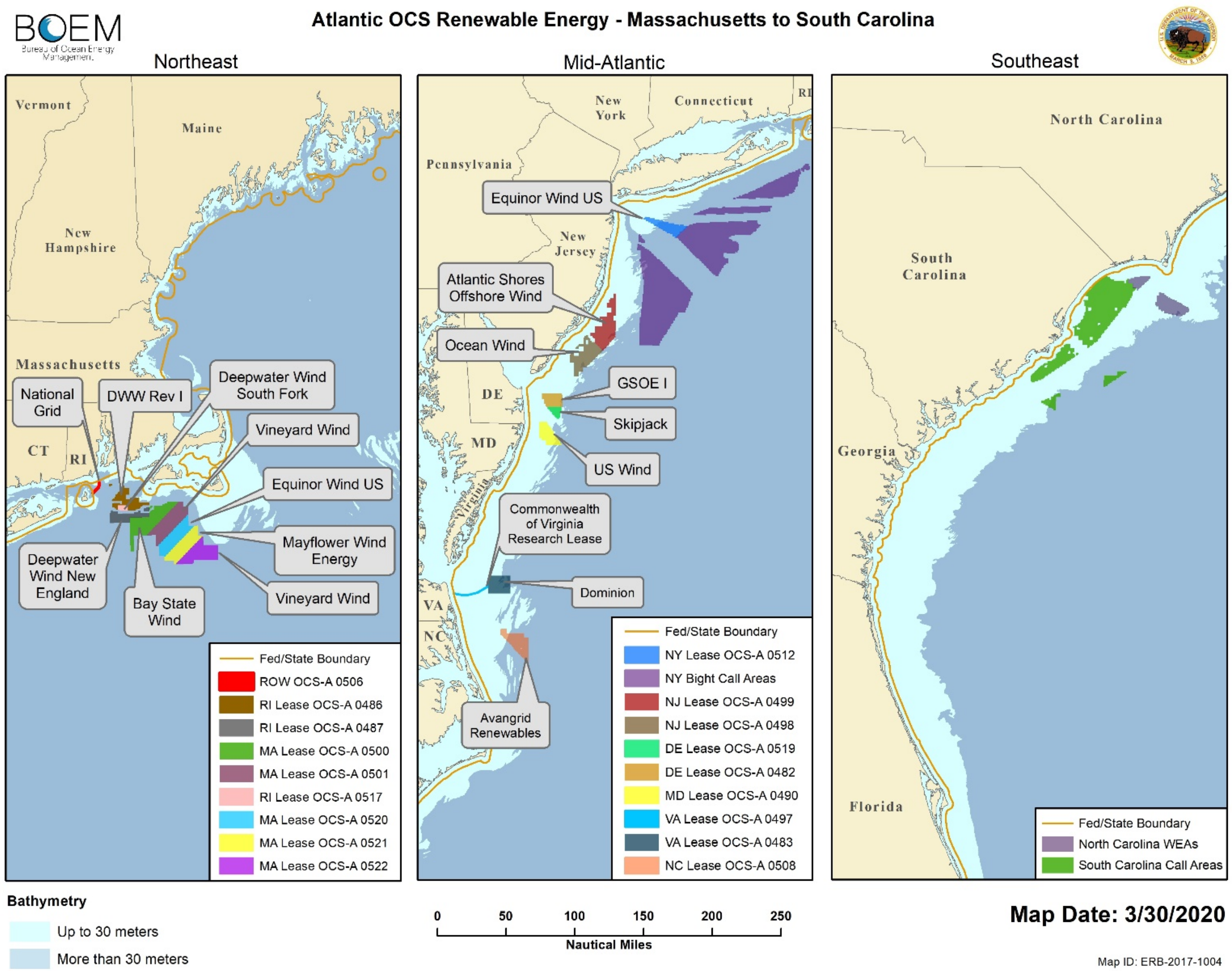
Elizabeth T. Methratta
IBSS Corp. in support of
Northeast Fisheries Science Center

NOAA FISHERIES

November 18, 2020
NYSERDA State of the Science



Offshore wind is advancing rapidly in the U.S.

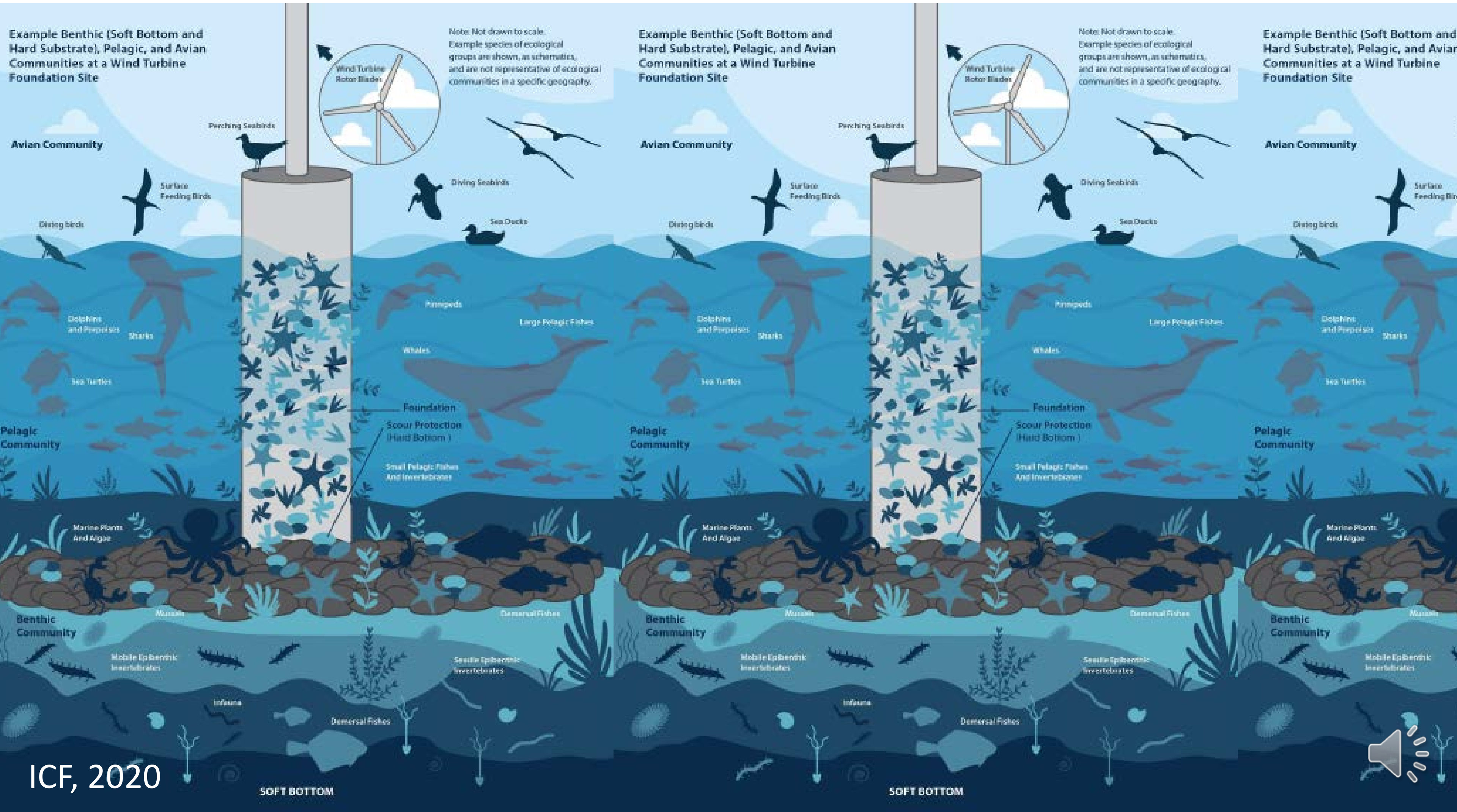


https://www.boem.gov/sites/default/files/images/Map%20of%20Atlantic%20OCS%20renewable%20energy%20areas.jpg

~2,000 Turbines

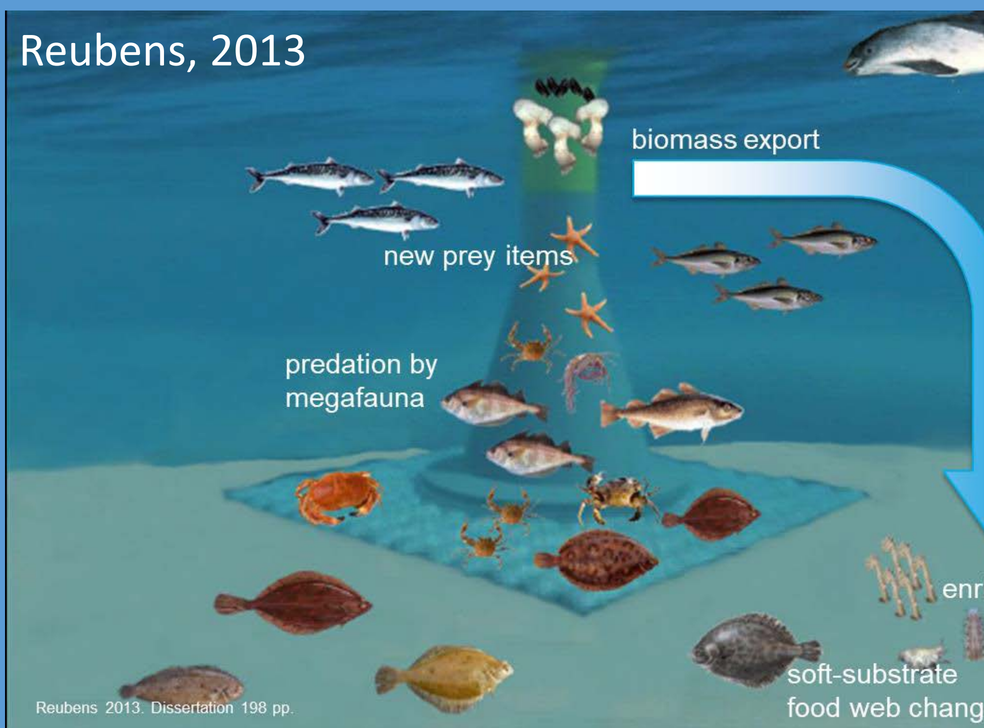
8,500 Km of Cable

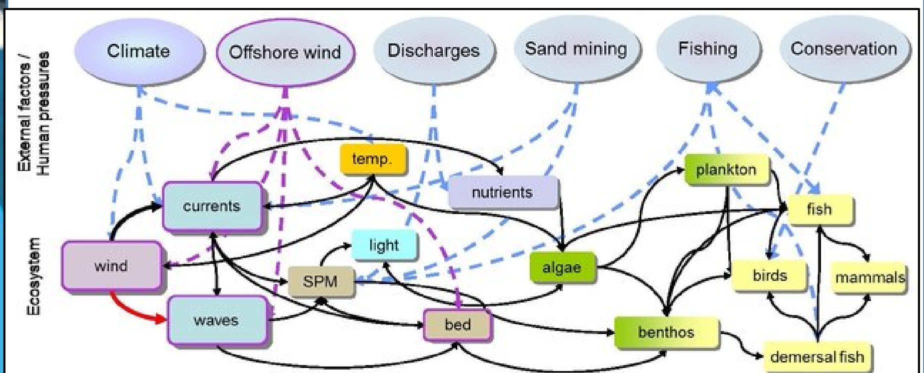
Offshore wind farms share the ocean with living marine resources



ICF, 2020

Interactions of OSW with the marine ecosystem are diverse





Boon et al., 2019 (ICES WG-MBRED)

Some ecological interactions are better studied than others

- **Knowledge Gaps for marine benthos (Danheim et al., 2019)**
  - Hydrodynamics effects on primary production and suspension feeders
  - Introduction and range expansion of non-natives
  - Noise and vibration effects
- **Knowledge Gaps for marine fish and shellfish (Synthesis of the Science, 2020)**
  - Effects on small and large pelagic fish and HMS
  - Production at the turbines; Contribution to regional productivity
  - Change in prey fields; Food web dynamics

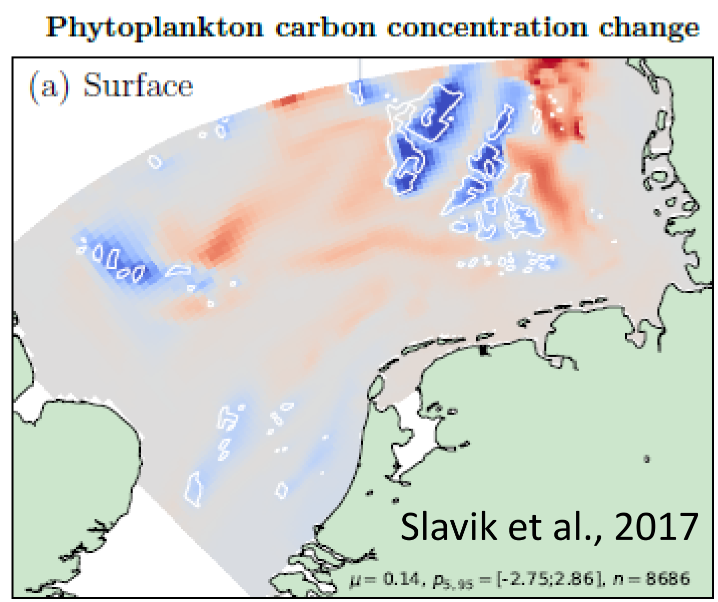
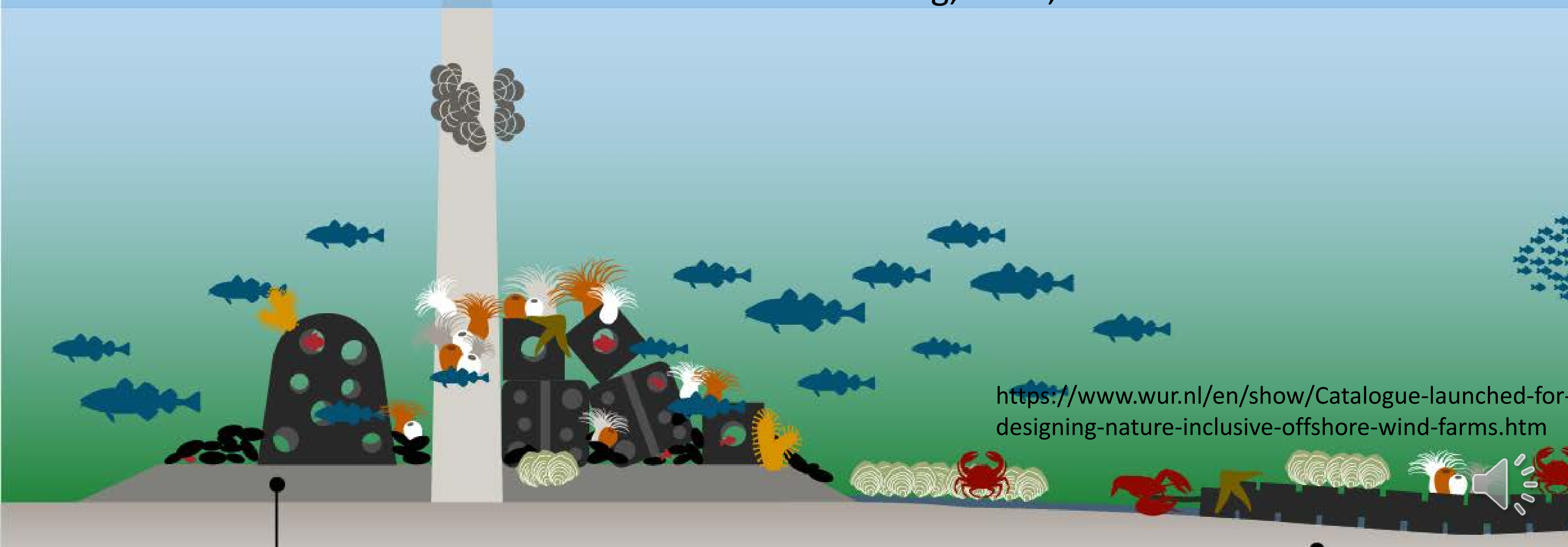


Fig. 6 Relative difference of phytoplankton stock (phytoplankton carbon concentration) between scenarios REF and OWF for the surface (a) and the bottom (b) layers on May 26, 2003 during the production peak.

‘Data-Rich, Information Poor’: Why is this a problem?

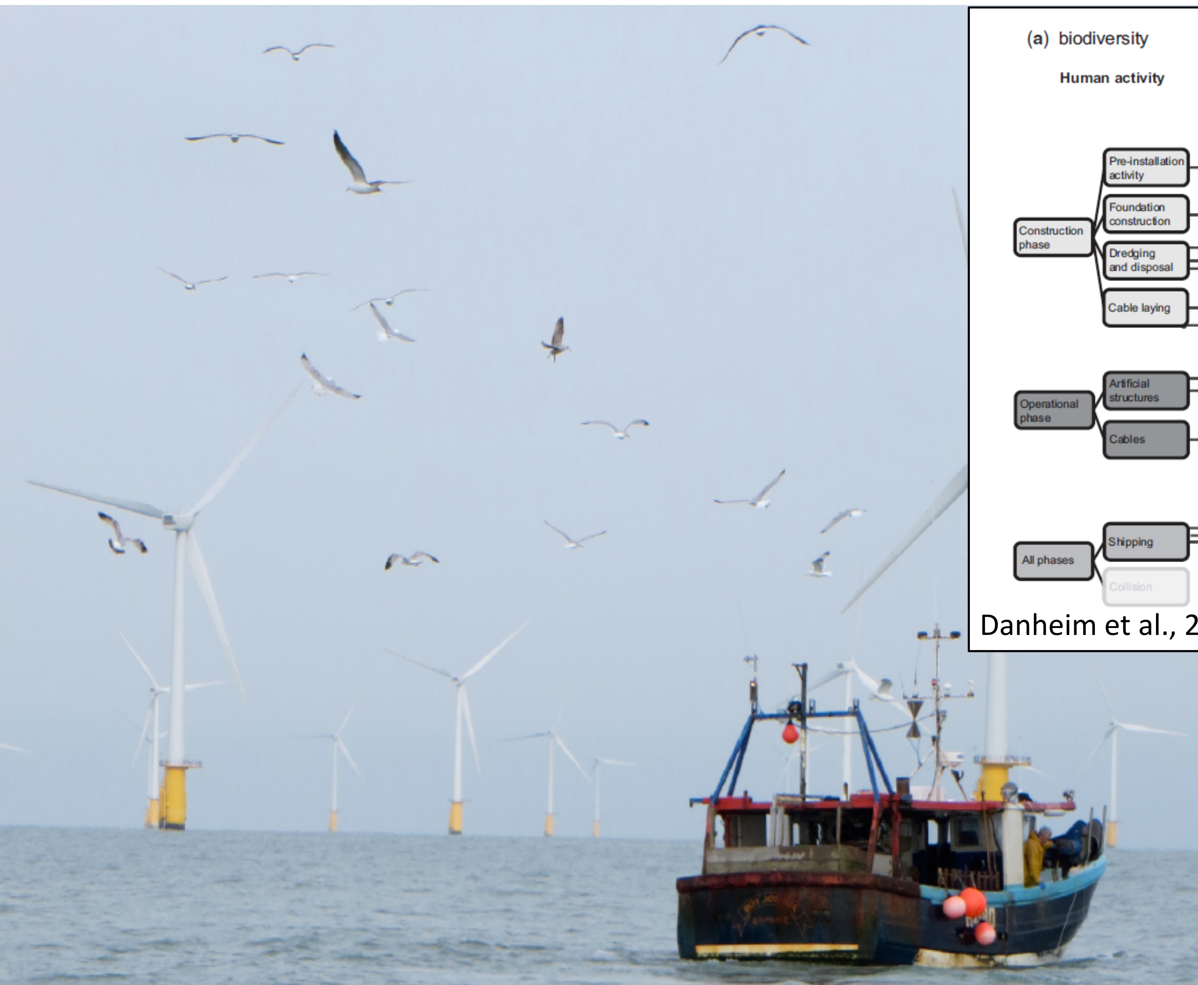
- 1991: First offshore wind farm installed off of Denmark

- “The benthos underpins crucial marine ecosystem services yet, in relation to MREDs, is currently poorly monitored: current monitoring programmes are extensive and costly yet provide little useful data in relation to ecosystem-scale-related changes, a situation called ‘data-rich, information-poor’ (DRIP).”
  – Wilding, et al., 2017

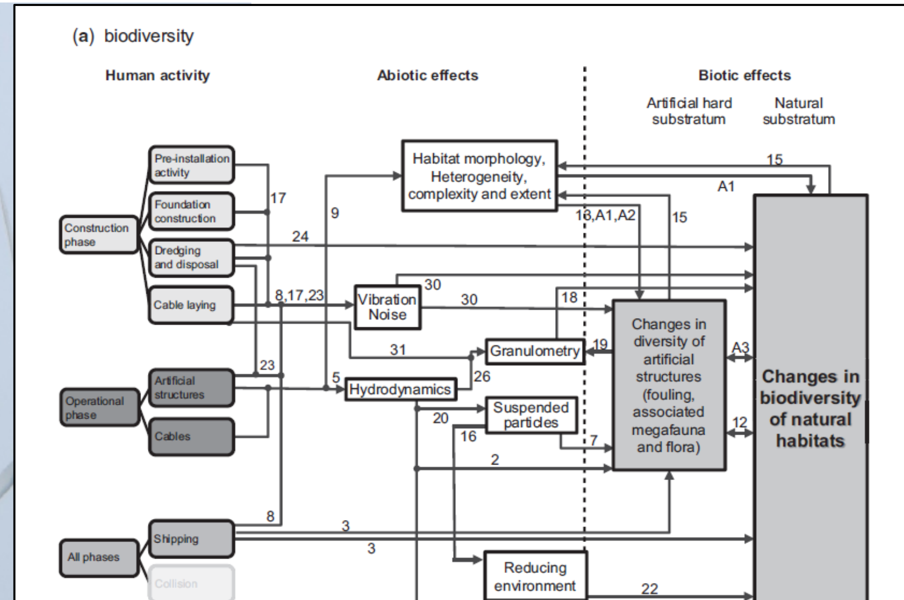


https://www.wur.nl/en/show/Catalogue-launched-for-designing-nature-inclusive-offshore-wind-farms.htm

In order to detect and understand the mechanistic basis of ecological effects, rigorous sampling designs are needed



https://www.nap.edu/read/25062/chapter/1

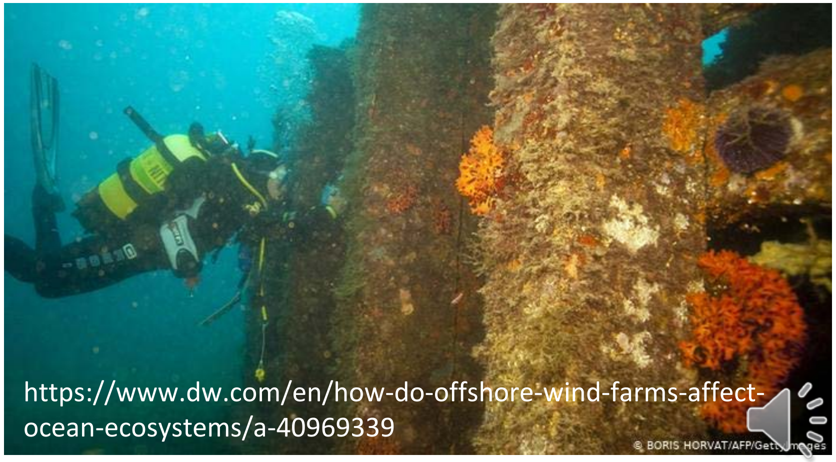


Danheim et al., 2019

Elements of an "information-rich" research and monitoring approach

1. Evaluate available data describing fishery resources and stressors within the project area
2. Define concise and appropriate monitoring objectives and hypotheses
3. Identify focus species (or groups) to monitor
4. Set indicators and define thresholds that are appropriate and measurable
5. **Design a plan to collect the appropriate data to address monitoring objectives**
6. **Analyze data collected to achieve monitoring objectives and test hypotheses**
7. Adjust sampling design/methods as needed to continue to address monitoring objectives
8. Store, share, disseminate data and results

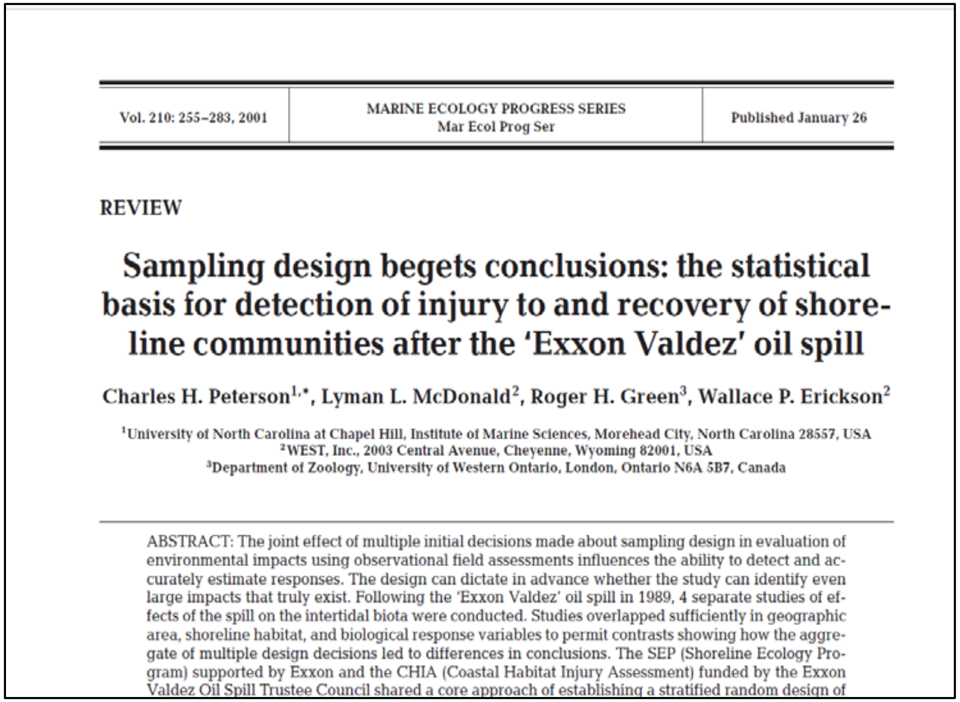
Draft ROSA IFRMWG monitoring guidelines, 2020



“Sampling design begets conclusions”

- “The joint effect of multiple initial decisions made about sampling design… influences the ability to detect and accurately estimate responses.”

--Peterson et al. 2001



Vol. 210: 255–283, 2001 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published January 26

REVIEW

Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the ‘Exxon Valdez’ oil spill

Charles H. Peterson[1,*], Lyman L. McDonald[2], Roger H. Green[3], Wallace P. Erickson[2]

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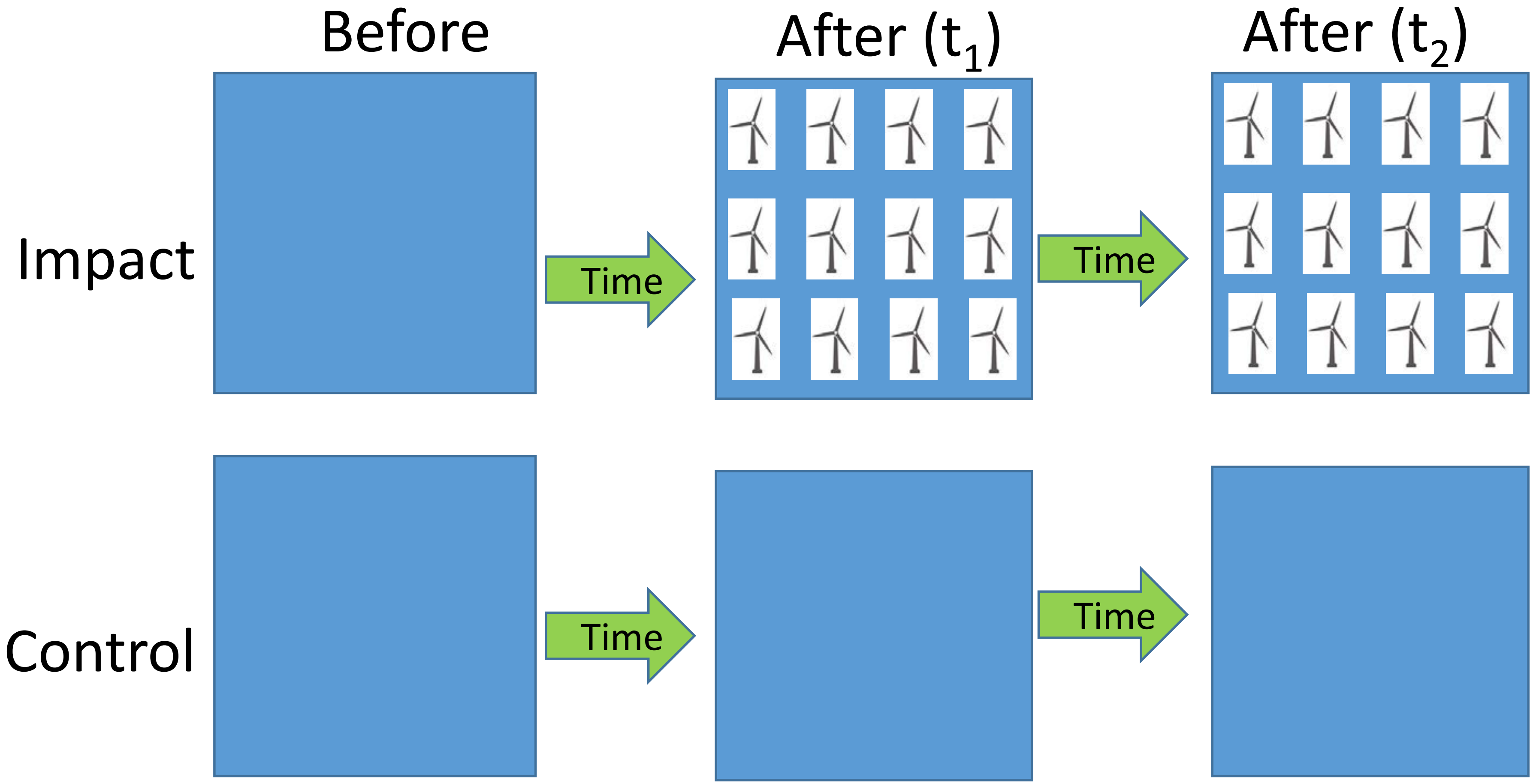
ABSTRACT: The joint effect of multiple initial decisions made about sampling design in evaluation of environmental impacts using observational field assessments influences the ability to detect and accurately estimate responses. The design can dictate in advance whether the study can identify even large impacts that truly exist. Following the ‘Exxon Valdez’ oil spill in 1989, 4 separate studies of effects of the spill on the intertidal biota were conducted. Studies overlapped sufficiently in geographic area, shoreline habitat, and biological response variables to permit contrasts showing how the aggregate of multiple design decisions led to differences in conclusions. The SEP (Shoreline Ecology Program) supported by Exxon and the CHIA (Coastal Habitat Injury Assessment) funded by the Exxon Valdez Oil Spill Trustee Council shared a core approach of establishing a stratified random design of

The most common study design: Before-After-Control-Impact (BACI)



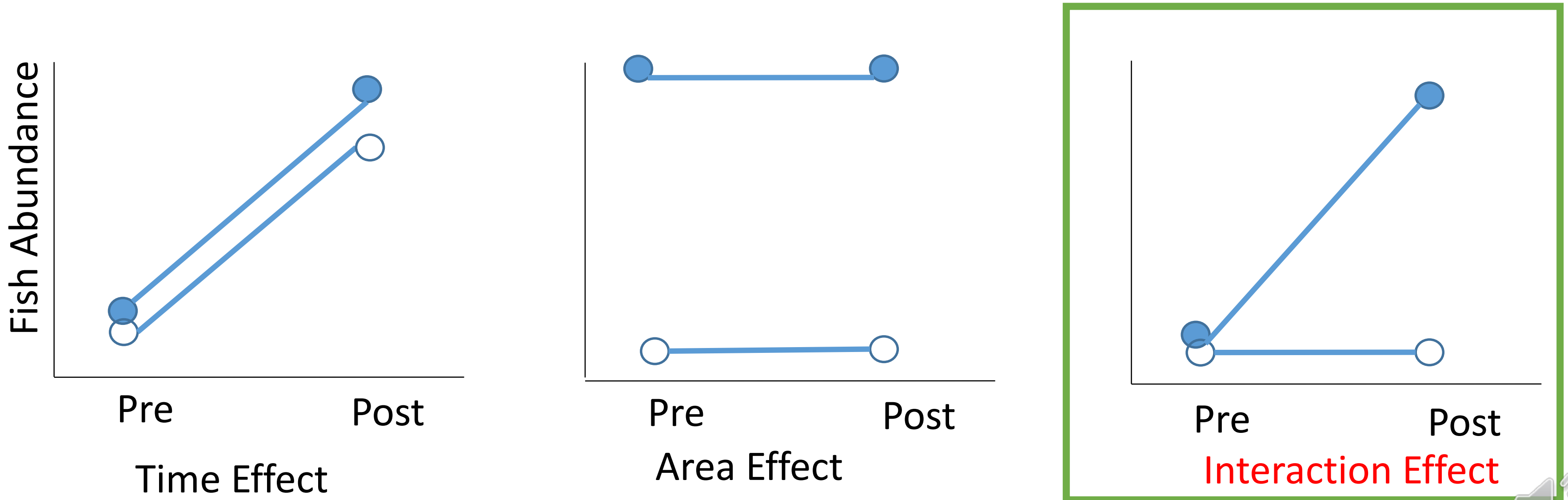
- Randomized site selection within 2 strata: impact and control
- Green, 1979; Stewart-Oaten et al., 1986; Underwood 1991, 1992, 1993, 1994

How is a significant OSW effect determined with a BACI design?

- 2-Way Analysis of Variance (ANOVA)

  <u>Main Effects of the Model</u>

  - Time (Before, After)
  - Area (Wind farm, Control)
  - **Time X Area Interaction**



Beyond BACI

- **Multiple controls** chosen randomly from a set of suitable controls to address spatial variability (Underwood 1991, 1992, 1993, 1994)
- **Sample at random time points** to address temporal variability (Underwood, 1991)
- **Sample paired impact-control sites** simultaneously to address spatial and temporal variability (Stewart-Oaten et al., 1986)

No broad consensus on how to deal with limitations of the BACI design

BACI Assumption #1:
Suitable controls can be found

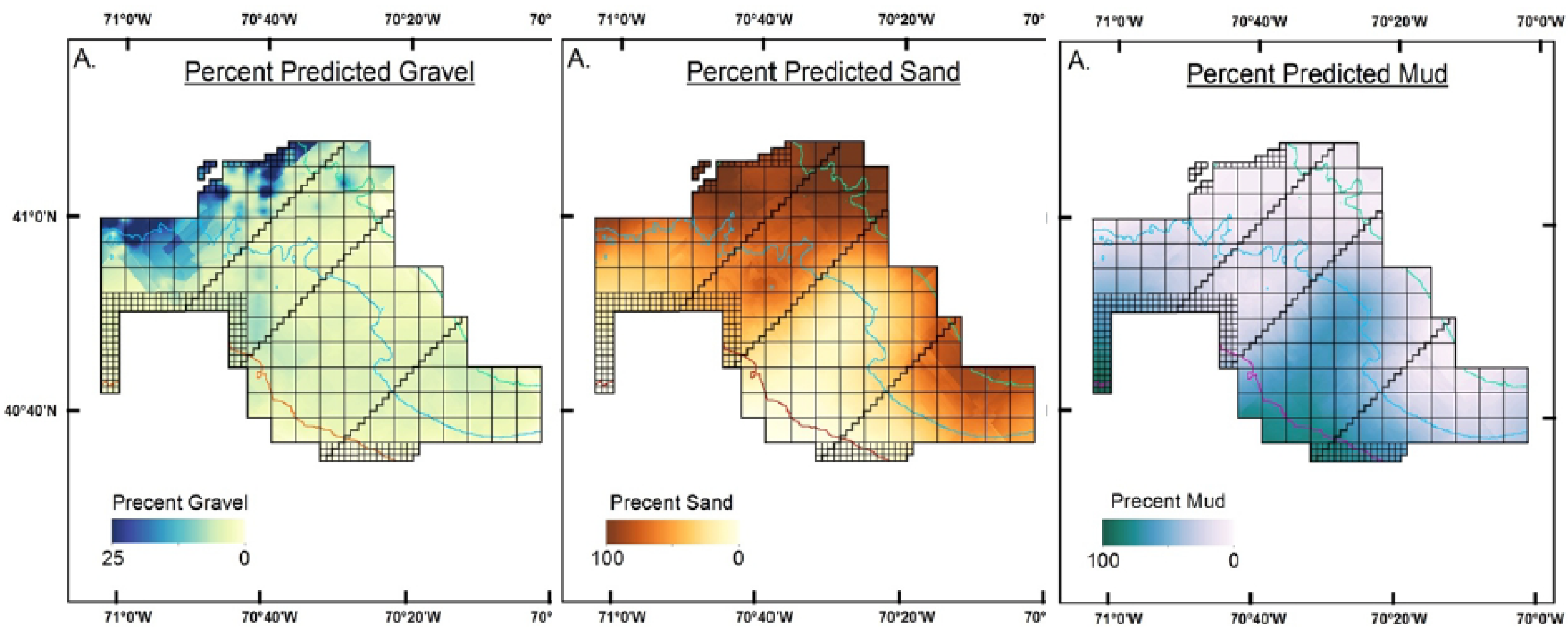
- <u>Criteria for a suitable control:</u>
  - Similar with regard to biological and physical habitat, fish abundance and distribution, exogenous factors
  - Close enough to be similar to impact site, but far enough away not to be affected by the impact
- <u>Why is this assumption a problem?</u>
  - Difficult to find controls in a dynamic system
  - Control and impact sites differ during baseline studies
  - Unexplained changes in the control over time
  - Control sites are slated for future development

BACI Assumption #2:
The area within the wind farm is homogenous

<u>Why is this assumption a problem?</u>

- Effect size attenuates with distance from turbines
- Wind energy areas are not biologically or physically homogenous

MA WEA



Guida et al., 2017

Gravel **Sand** **Mud**

BACI Assumption #3:
The spatial scale of the effect is known

<u>Why is this assumption a problem?</u>

- The scale of effect is not well understood because we lack a mechanistic understanding of individual stressors
- “Wind farm effect” is often treated in aggregate, even though individual stressors operate over different scales. Some examples-→

https://www.rechargenews.com/wind/will-wind-wake-slow-industrys-ambitions-offshore-/2-1-699430

Examples of Stressors	Scale of Direct Effects	Scale of Indirect Effects	References
Addition of new hard bottom habitat	up to 50 m	?	Bergstrom et al., 2014
Change in sediment organic content	up to 200 m	?	Danheim et al., 2020
Wind wakes	Up to 80 km	?	Schrum et al., 2019
Change in fishing patterns	?	?	?

Majority of ecological studies at OSWs have used BACI or CI design

- 32 Field studies summarized
  - 12 CI (Control-Impact)
  - 12 BACI
  - 8 targeted studies with no controls

Table 2. Summary of studies using BACI, CI, and Impact Location Only methods at offshore wind farms and whether distance from the turbines was examined

Water body	Country	Distance from turbine studied (yes/no)	Distance effect detected (yes/no)	Response variables examined	Citation
BACI					
Baltic Region (Øresund)	Sweden	Yes; depending on the year of sampling: 130–1,350 m, 20–140 m	Yes	Species biomass, richness, and diversity; community composition of demersal fish	Bergström *et al.* (2013)[a]
Baltic Sea/ Kattegat Region	Denmark	No	NA	Abundance and density of demersal, bentho-pelagic, and pelagic fish, and movement patterns for common eel (*Anguilla anguilla*)	DONG Energy *et al.* (2006)[b]
North Sea	Belgium	Yes: sites inside wind farm at 200 m from turbine and just outside wind farm	In some instances	Species density, biomass, richness, fish length of demersal, and bentho-pelagic fish	Degraer *et al.* (2012, 2016, 2018)[b]
North Sea	Belgium	Yes: sites inside wind farm at 200 m from turbine and just outside wind farm	In some instances	Species density, biomass, richness and fish length of demersal and bentho-pelagic fish	Vandendriessche *et al.* (2015)[a]
North Sea	Belgium	No	NA	Gut content analysis of lesser weever (*Echiichthys vipera*), dab (*Limanda limanda*), and whiting (*Merlangius merlangus*)	Degraer *et al.* (2016)[b]
North Sea	Denmark	No	NA	Abundance and density of demersal, bentho-pelagic, and pelagic fish	DONG Energy *et al.* (2006)[b]
North Sea	Denmark	Yes: 1–100, 120–220, and 230–330 m	Yes	Species abundance and diversity and fish length of demersal, pelagic, and rocky habitat fish	Stenberg *et al.* (2015)[a]
North Sea	Denmark	No	NA	Density of juvenile and adult sand eel species; habitat	van Deurs *et al.* (2012)[a]
North Sea	Germany	No	NA	Species abundance and diet of mackerel (*Scomber scombrus*)	Lüdeke (2015)[b] and Krägefsky (2014)[b]
North Sea	Netherlands	No	NA	Species abundance and richness of demersal fish	Hillie Ris Lambers and ter Hofstede (2009)[b]
North Sea	Netherlands	No	NA	Abundance of demersal and pelagic fish	Lindeboom *et al.* (2011)[a]
Northwest Atlantic Ocean	United States	No	NA	Abundance, fish length, and condition for flatfish	Wilber *et al.* (2018)[a]
CI					
Baltic Sea	Sweden	Yes: sites at 0, 1–5, and 20 m, from turbine and reference	Yes	Species abundance, richness, and diversity of demersal fish	Wilhelmsson *et al.* (2006)[a]
Baltic Region (Kalmaar Strait)	Sweden	Yes: sites at 0, 1, and 20 m from turbines	Yes	Species abundance and density for adults and juveniles of all fish in the community	Andersson and Öhman (2010)[a]
Baltic Region (Øresund)	Sweden	No	NA	Fish length, weight, histosomatic index, gonadosomatic index, condition index and population size for Eelpout (*Zoarces viviparous*)	Langhamer *et al.* (2018)[a]
Irish Sea	Ireland	No; all sites within 200 m from turbine	NA	Species abundance, richness, diversity of demersal fish	Atalah *et al.* (2012)[a]
Irish Sea	United Kingdom	Yes: sites at 0 and 100 m from turbines	Yes	Species abundance and richness of all fish	Griffin *et al.* (2016)[a]
North Sea	Belgium	No	NA	Gut content analysis of lesser weever (*E. vipera*), horse mackerel (*Trachurus trachurus*), solenette (*Buglossidium luteum*), dragonet (*Callionymus* sp.), dab (*L. limanda*), and whiting (*M. merlangus*)	Degraer *et al.* (2012)[b]

Continued

Methratta, 2020

Alternatives to the simple BACI design are needed to detect ecological effects

- "We learned that basic monitoring by itself (e.g. following the BACI design of OWP versus reference area) is not sufficient to disentangle specific cause– effect relationships, especially in systems with a high natural variability (Gray & Elliot, 2009; Lindeboom et al., 2011)."
  - Lindeboom et al., 2015

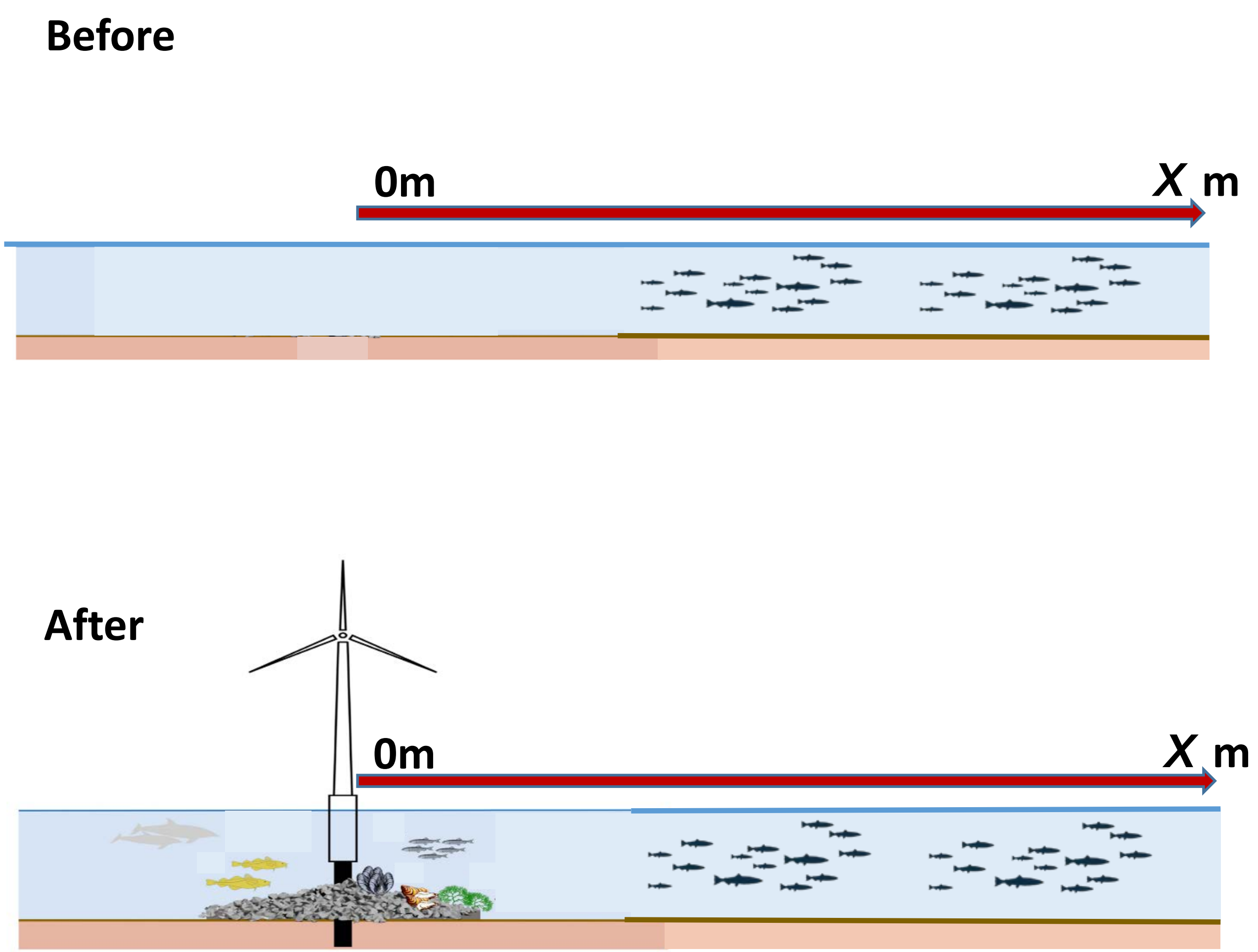
How can sampling designs be improved?

Challenges	Potential Solutions	
BACI Assumptions	**Adapted BACI**	**Before-After-Gradient (BAG)**
• #1: Suitable controls can be found	• NA	
• #2: The area within the wind farm is homogenous	• Stratify sampling areas by environmental variables	
• #3: The spatial scale of the effect is known	• For randomly sampled sites, record nearest-neighbor distance to turbine	

Based on Methratta, 2020. *ICES JMS* 77: 890-900

Before-After-Gradient (BAG)

- Ellis and Schneider, 1997

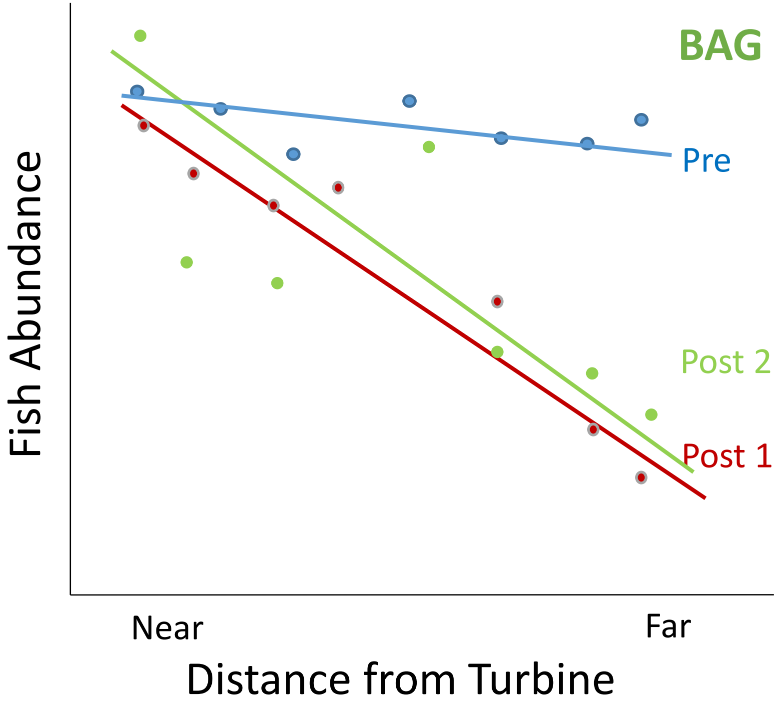


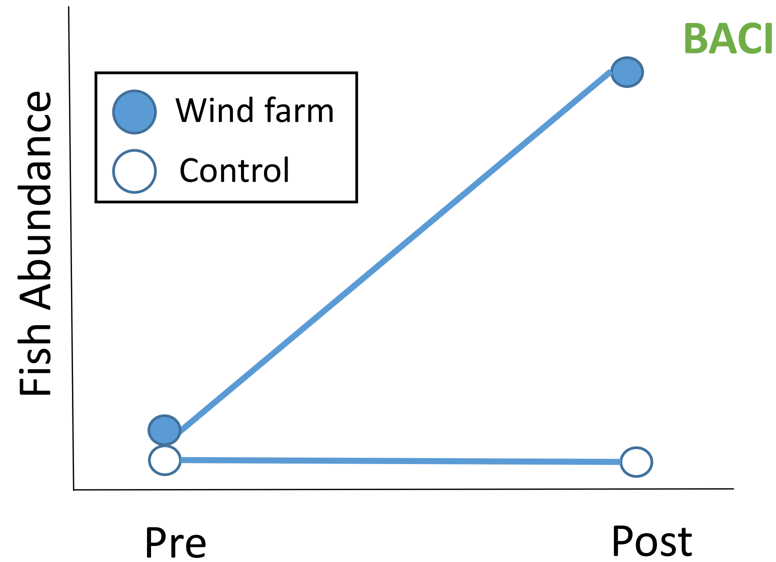
Based on Glarou et al., 2020

- Measure response variables and covariates along a spatial gradient before and after the impact and incorporate that information into statistical models

How is a significant OSW effect determined with BAG?

- BAG examines how the distance vs. dependent variable relationship changes over time.
- BACI examines the change in effect size over time between impact and control strata
- Analytical approach depends on assumptions, e.g., is a linear or non-linear relationship expected between dependent and independent variables?
- Gradient study examples
  - Ellis and Schneider, 1997 (Gradient – "After" data only)
  - Brandt et al., 2011 (Before-After-Gradient)
  - Rothermel et al., 2020 (Gradient – "Before" Data only)





Gradient design was more powerful than CI design for detecting impacts on benthic invert density - **Ellis and Schneider, 1997**

- Sampled at 23 different distances from structure
- Compared gradient vs. CI analytical approach with the same data
- Equal sample sizes used for each comparison
- "After" data only
- Gradient design had greater statistical power than CI design to detect differences

Model	Distances from oil platform (m)	df	F	p	Power
Near Oil Platform Sites Only (<=1000m)					
Gradient	100, 150, 250, 330, 460, 500, 1000	1	5.68	0.0172	0.86
CI Block	Impact = 100; Control=1000	1	5.05	0.0247	0.81
All Sites					
Gradient	100, 150, 250, 330, 450, 460, 500, 750, 800, 850, 1000, 1200, 1300, 1800, 1900, 2500, 3300, 3900, 4000, 4000, 5700, 5800, 6500	1	4.49	0.034	0.76
CI Block	Impact = 100-460; Control=1000-2500	1	1.82	0.1771	0.3
CI Block	Impact = 100-460; Control=1000-6500	1	1.99	0.1582	0.3

Ellis and Schneider et al., 1997

BAG demonstrated change in porpoise activity patterns with distance from pile driving – **Brandt et al., 2011**

- Horns Rev II, Denmark; 92 turbines, arranged in 7 rows; 35 km2
- Studied response of harbor porpoise (*Phocoena phocena*) to pile driving
- Passive acoustic monitoring devices deployed along a gradient of increasing distance from pile driving event (2.5, 3.2, 4.8, 10.1, 17.8, 21.2 km).
- During pile driving, period of reduced activity decreased with increasing distance out to 17.8 km; Little reduced activity at 22 km
- Out to 4.7 km, recovery time was longer than pauses between pile driving events
- “Before” and “After” data

Table 4. Mean porpoise activity (porpoise positive minutes per hour, PPM/h) in the first hour after pile driving (Hpd), overall means and means for all hours >70 Hpd, for each POD position. Sample sizes are given in brackets. The change in PPM/h during the hour after pile driving relative to the other 2 means is also shown

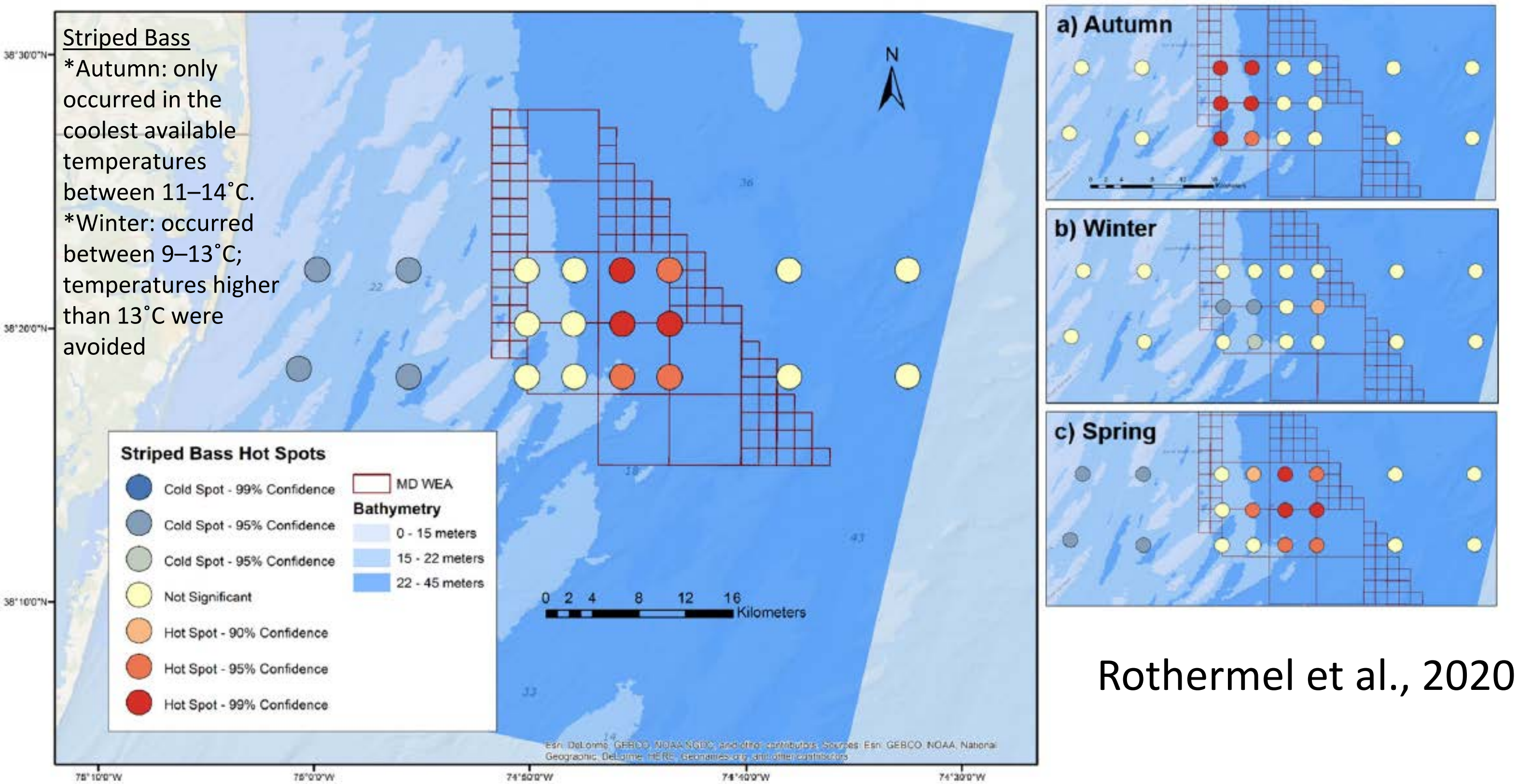
POD position	Mean PPM/h 1 Hpd	Mean PPM/h Overall	Mean PPM/h >70 Hpd	Change (%)
1	0.0 (70)	0.9 (3192)	1.8 (356)	–100
2	0.0 (36)	1.0 (2304)	1.0 (207)	–100
3	0.0 (37)	1.1 (2400)	0.6 (232)	–100
4	3.9 (51)	6.2 (1896)	5.7 (328)	–32 to –37
5	2.9 (70)	4.3 (3528)	5.7 (356)	–33 to –49
6	4.6 (54)	4.7 (3505)	3.5 (356)	–2 to +31

Table 2. Results from the GAM on the effects of 4 independent variables on porpoise activity (porpoise positive minutes per hour, PPM/h). F-values and estimated degrees of freedom (edf) are given; the p-value of the main effect to be tested is indicated in **bold**. The model explained 27.9% of the overall variance in the data

POD=passive acoustic monitoring device

Independent variable	F	edf	p
Hour after pile driving × POD position	13.5	28.0	**< 0.0001**
Distance	195.1	8.9	< 0.0001
Time of day	6.9	8.4	< 0.0001
Month	41.3	4	< 0.0001

Gradient study reveals cross-shelf migration patterns across the MD WEA – **Rothermel et al., 2020**



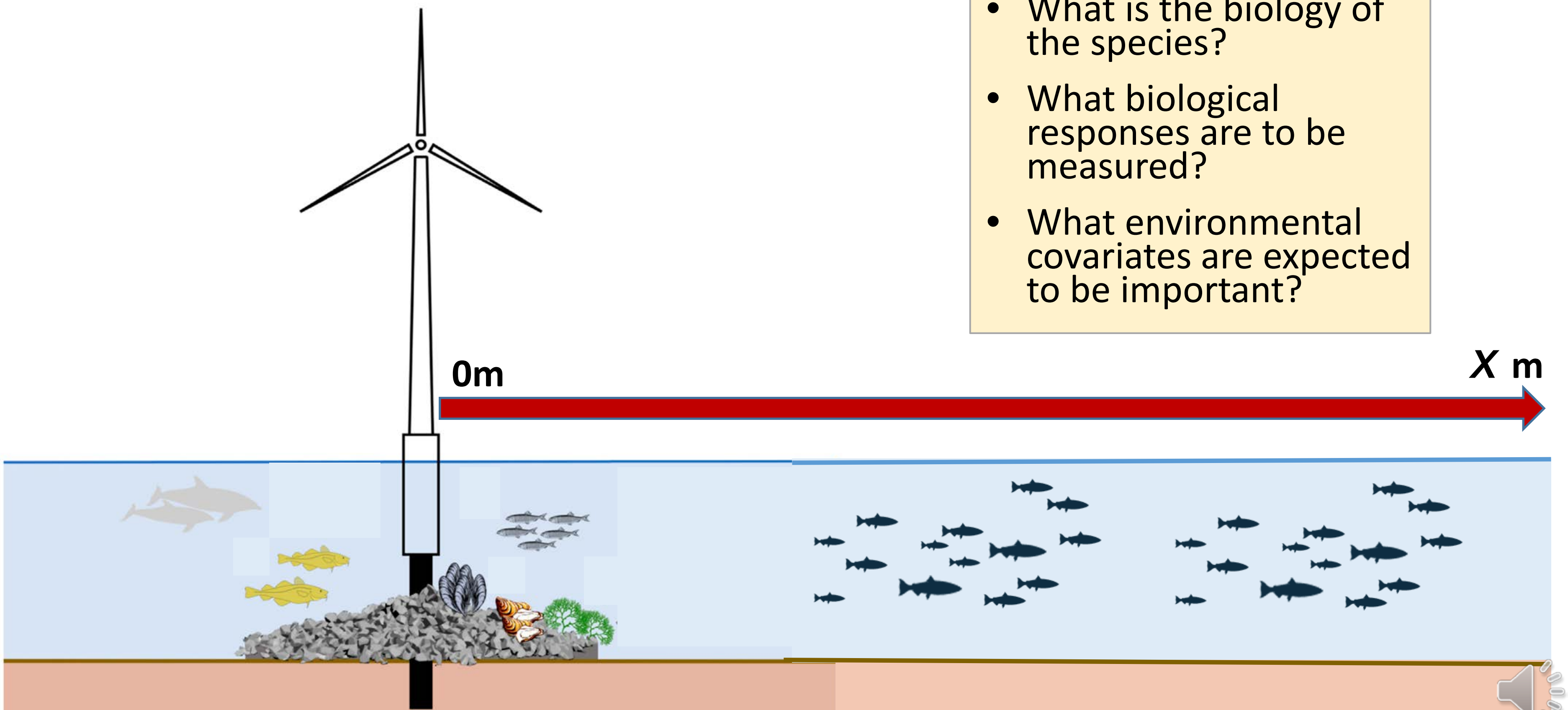
Rothermel et al., 2020

Fig 4. Hot spots of species occurrence across the acoustic receiver array. Results reflect annual (left) and seasonal (insets, right) numbers of individual Atlantic sturgeon (top) and striped bass (bottom) detected per receiver.

- Placed acoustic telemetry receivers across a gradient in bathymetry, temperature, and other environmental variables
- Monitored seasonal incidence and movement behavior across gradients
- "Before" data only

Gradient designs could be a powerful tool to study OSW effects on fisheries resources

- What is the hypothesis being tested?
- What species or species groups?
- What is the biology of the species?
- What biological responses are to be measured?
- What environmental covariates are expected to be important?



Based on Glarou et al., 2020

How can sampling designs be improved?

Challenges	Potential Solutions	
BACI Assumptions	**Adapted BACI**	**Gradient / BAG**
• #1: Suitable controls can be found	• NA	• Does not use controls
• #2: The area within the wind farm is homogenous	• Stratify sampling areas by environmental variables	• Gradient sampling incorporates spatial heterogeneity into design
• #3: The spatial scale of the effect is known	• For randomly sampled sites, record nearest-neighbor distance to turbine	• Gradient sampling can help to determine the spatial scale of effects

Based on Methratta, 2020. *ICES JMS 77*: 890-900

BAG assumption to be addressed

- Location of to-be-built turbines are known during the "before" time period

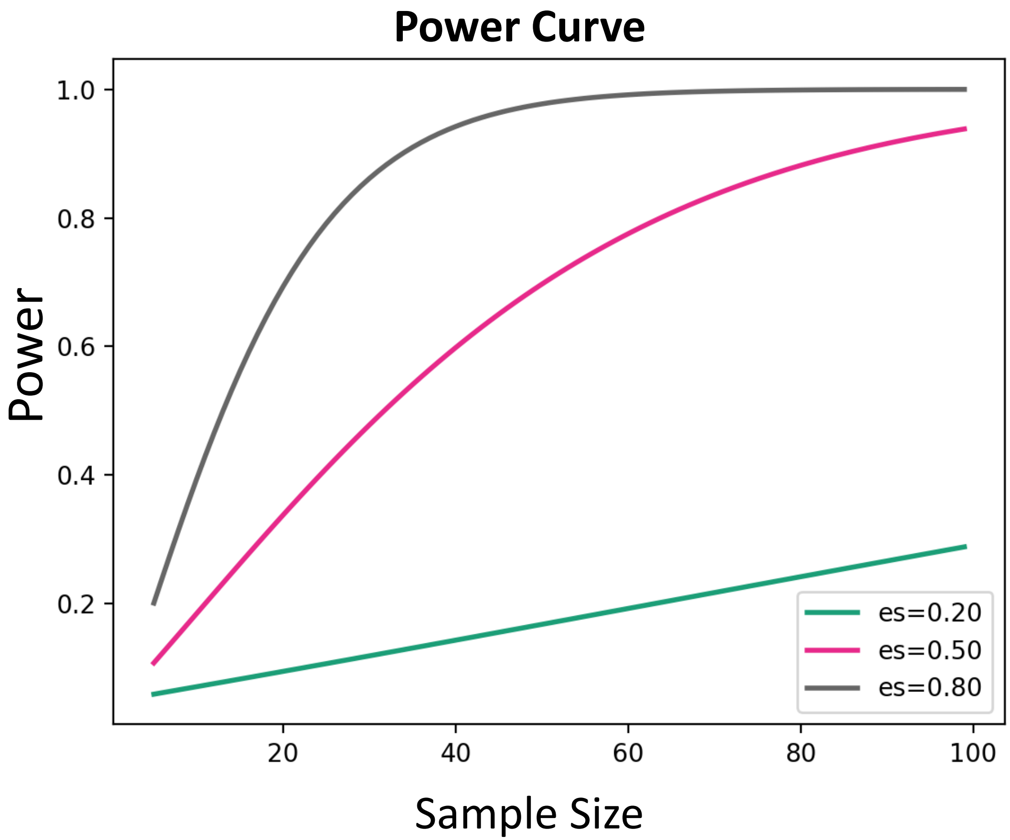
This is a solvable human issue not an inherent design issue.

https://fortune.com/2019/10/07/offshore-wind-uk-auction-subsidies/

Other Critical Design Considerations

- Sample size determination and power analysis

- Random sites:
  - Good for assessing status of the overall area
  - Increased spatial variance can make it difficult to assess temporal trends
- Fixed sites:
  - Good for assessing temporal trends because spatial variance is minimized
  - Difficult to generalize to other locations
- Both Random and Fixed Sites
  - Might there be some utility in incorporating both?



es=Effect Size

https://machinelearningmastery.com/statistical-power-and-power-analysis-in-python/

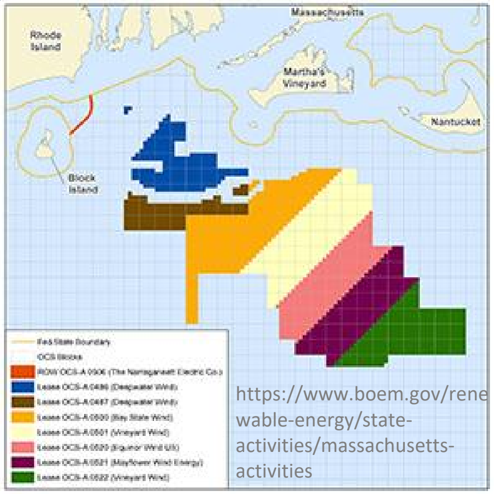
Other Critical Design Considerations (cont.)

- How to scale turbine-level and wind-farm level data up to the region and ecosystem level
  - Integrate with regional scientific surveys
  - Calibrate sampling methodologies and modalities
  - Establish a regional framework for monitoring → ROSA

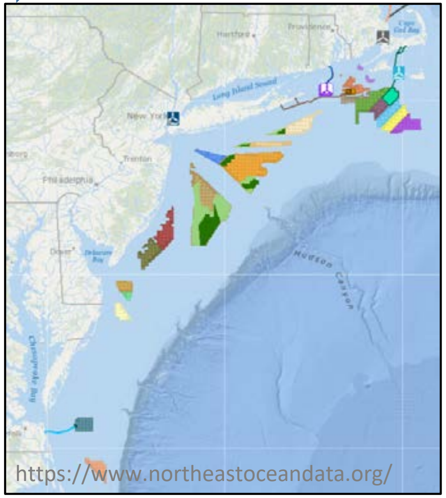
Turbines

Wind Farm

Region



Ecosystem



Take Home Messages

- Research question and/or monitoring goals should guide study design.
- Simple CI and BACI designs make several assumptions that present challenges to their application to study the ecological impact of offshore wind development.
- Gradient designs (BAG) can offer a powerful alternative to traditional BACI designs.

Thank you!

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