Statistical power in testing marine fauna displacement due to an offshore wind farm

B. Pérez Lapeña, K.M. Wijnberg, A. Stein and S.J.M.H. Hulscher

UNIVERSITY OF TWENTE.
we@sea

Outline

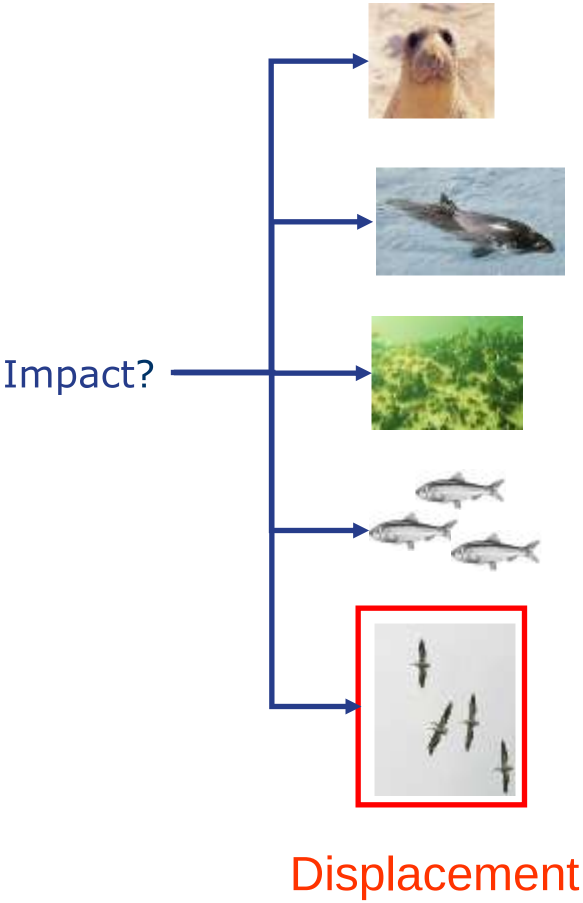
- Offshore wind energy in Netherlands and impact assessment
- Statistical power analysis
- Effect of spatial factors on statistical power
- Suitable number of surveys
- Conclusions

Dutch offshore wind energy

- Dutch national target:
  - 20% renewable energy production by 2020
  - 6000 MW installed capacity offshore
  - Requires 1200 wind turbines at sea

- Current situation
  - 2 offshore wind farms
  - 228 MW installed capacity
  - 96 wind turbines at sea

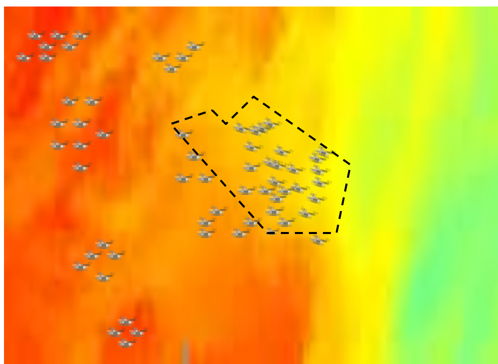
Framework



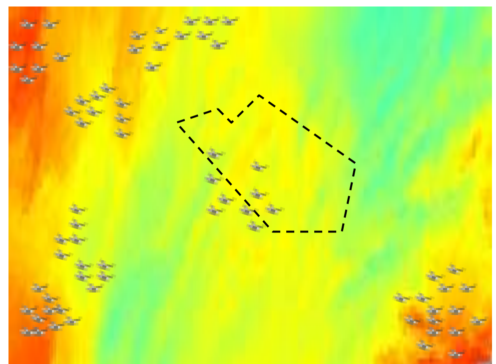
Simulation-based method

$$H_0 : \left(\frac{\mu_{wf}}{\mu_c}\right)_{REF} = \left(\frac{\mu_{wf}}{\mu_c}\right)_{POST}$$

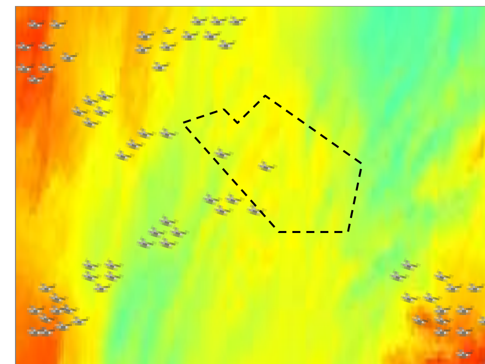
Pre-construction situation



Reference situation



Post-construction data



Predict

Compare

Build a geostatistical model:

- Seabird abundance in relation to environmental factors
- Spatial autocorrelation
- Zero-inflation in seabird data

Construct many realizations

Is post-construction data statistically different from the reference situation?

Errors in conclusion about impact

- Marine environment is a complex system
- Conclusions about impact are subject to errors

Result hypothesis test

Truth		You conclude 'YES IMPACT'	You conclude 'NO IMPACT'
Truth	'NO IMPACT'	✗ **Type I error with probability α**	✓ **Correct decision**
Truth	'IMPACT'	✓ **Correct decision**	✗ **Type II error with probability β**

Type II error → Power analysis

Power analysis

- Technique to determine β (the probability of committing a Type II error)
  - Probability of concluding ‘no impact’ when the reality is ‘impact’
- Statistical power:
  - 1- β
  - Probability of concluding ‘impact’ when the reality is ‘impact’
- For the post-construction situation: we impose a decrease in the mean number of birds in the wind farm area
- We apply the impact assessment method to each simulated survey
- We count the number of times that we correctly conclude ‘impact’
  - This gives 1- β

Example scenarios and power results

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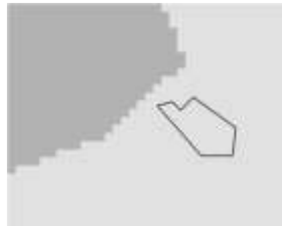
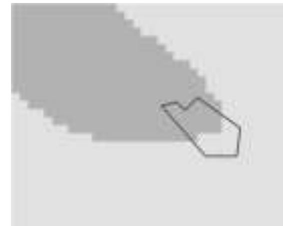
EC1

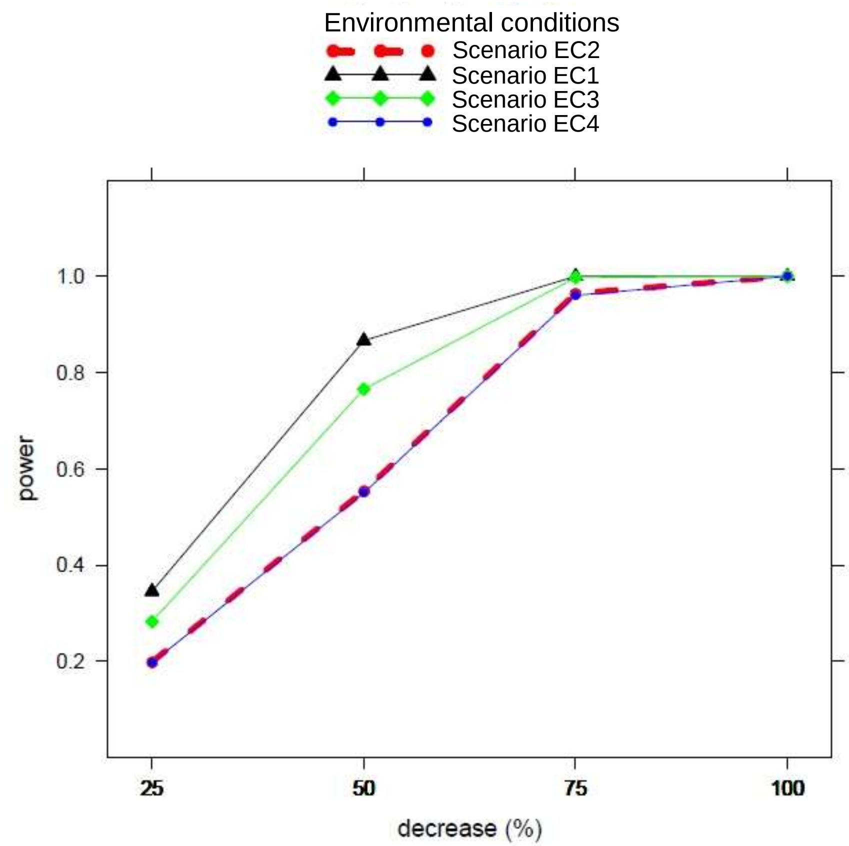
EC2



EC3



EC4



Number of surveys

What is a suitable number of surveys to best distinguish between impact/no impact?

- Using the quantified probabilities to commit errors:
  - Type I: α
  - Type II: β

- Using Bayes' theorem

- Calculate the probability that impact exists based on N positive outcomes ('YES IMPACT') after *k* surveys

Number of surveys – example (I)

- Calculate $P(\Theta = y|N_k)$

  The probability that impact exists based on N positive (y) outcomes after *k* surveys

  Θ = existence of impact (Θ=y or Θ=n)

- Two surveys ($k = 2$)
- $\alpha = 0.05$, power $(1-\beta) = 0.8$

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy				
yn or ny				
nn				

Number of surveys – example (I)

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- N_2 is the number of positive outcomes (y) after 2 surveys

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
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- N_2 is the number of positive outcomes (y) after 2 surveys

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy	2			
yn or ny	1			
nn	0			

Number of surveys – example (I)

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- $P(N_2|\Theta = y)$ is the probability of N positive outcomes (N_2) if impact exists

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
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Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy	2	$0.8 \cdot 0.8 =$ 0.64		
yn or ny	1	$2 \cdot (0.8 \cdot 0.2) =$ 0.32		
nn	0	$0.2 \cdot 0.2 =$ 0.04		

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Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
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nn	0	$0.2 \cdot 0.2 =$ 0.04		

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Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy	2	$0.8 \cdot 0.8 =$ 0.64	$0.05 \cdot 0.05 =$ 0.0025	
yn or ny	1	$2 \cdot (0.8 \cdot 0.2) =$ 0.32	$2 \cdot (0.05 \cdot 0.95) =$ 0.0475	
nn	0	$0.2 \cdot 0.2 =$ 0.04	$0.95 \cdot 0.95 =$ 0.9025	

Number of surveys – example (I)

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  The probability that impact exists based on N positive (y) outcomes after *k* surveys

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy	2	$0.8 \cdot 0.8 =$ 0.64	$0.05 \cdot 0.05 =$ 0.0025	
yn or ny	1	$2 \cdot (0.8 \cdot 0.2) =$ 0.32	$2 \cdot (0.05 \cdot 0.95) =$ 0.0475	
nn	0	$0.2 \cdot 0.2 =$ 0.04	$0.95 \cdot 0.95 =$ 0.9025	

Number of surveys – example (I)

- Calculate P(Θ = y|N_k)

  The probability that impact exists based on N positive (y) outcomes after *k* surveys

- Bayes' theorem

$$P(\Theta = y \mid N_2) = \frac{P(N_2 \mid \Theta = y)P_y}{P(N_2 \mid \Theta = y)P_y + P(N_2 \mid \Theta = n)P_n}$$

Outcome impact assessment	N_2	P(N_2|Θ = y)	P(N_2|Θ = n)	P(Θ = y|N_2)
yy	2	0.8·0.8 = 0.64	0.05·0.05 = 0.0025	
yn or ny	1	2·(0.8·0.2) = 0.32	2·(0.05·0.95) = 0.0475	
nn	0	0.2·0.2 = 0.04	0.95·0.95 = 0.9025	

Number of surveys – example (I)

- Calculate $P(\Theta = y|N_k)$

  The probability that impact exists based on N positive (y) outcomes after *k* surveys

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- A priori probabilities on existence of impact: P_n and $P_y = 0.5$

Outcome impact assessment	N_2	$P(N_2\|\Theta = y)$	$P(N_2\|\Theta = n)$	$P(\Theta = y\|N_2)$
yy	2	$0.8 \cdot 0.8 =$ 0.64	$0.05 \cdot 0.05 =$ 0.0025	
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Number of surveys – example (I)

- Calculate $P(\Theta = y|N_k)$

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- Bayes' theorem

$$P(\Theta = y \mid N_2) = \frac{P(N_2 \mid \Theta = y)P_y}{P(N_2 \mid \Theta = y)P_y + P(N_2 \mid \Theta = n)P_n}$$

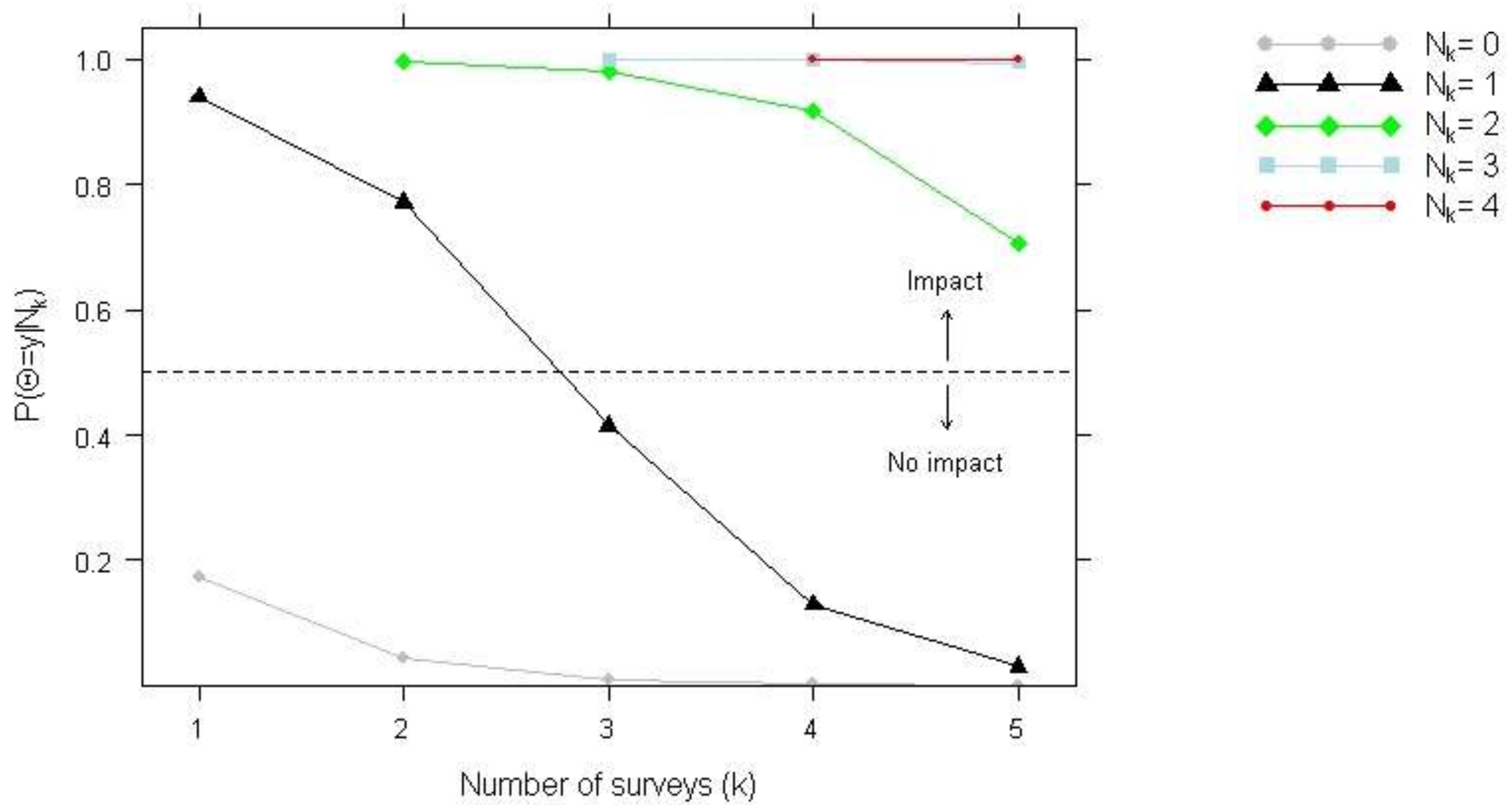
- A priori probabilities on existence of impact: P_n and $P_y = 0.5$

Outcome impact assessment	N_2	$P(N_2 \mid \Theta = y)$	$P(N_2 \mid \Theta = n)$	$P(\Theta = y \mid N_2)$
yy	2	$0.8 \cdot 0.8 =$ 0.64	$0.05 \cdot 0.05 =$ 0.0025	0.996
yn or ny	1	$2 \cdot (0.8 \cdot 0.2) =$ 0.32	$2 \cdot (0.05 \cdot 0.95) =$ 0.0475	0.771
nn	0	$0.2 \cdot 0.2 =$ 0.04	$0.95 \cdot 0.95 =$ 0.9025	0.042

Number of surveys – example (II)

Arbitrary number of surveys:

$$P(\Theta = y \mid N_k) = \frac{P(N_k \mid \Theta = y)P_y}{P(N_k \mid \Theta = y)P_y + P(N_k \mid \Theta = n)P_n}$$



Conclusions

- Factors affecting the ability to detect impact:
  1) Environmental conditions at the time of the survey
  2) Survey effort and design
  3) Seabird abundance
  4) Spatial autocorrelation

- Probability of committing type I and type II errors

+

Bayes' theorem

We can advice environmental managers on a suitable number of surveys after wind farm construction


Comments? Questions?