Ecological risk assessment frameworks: A spectrum of approaches, assumptions, and applications

Challenges & opportunities in marine mammal case studies

Saana Isojunno & Brandon Southall, DOSITS Oct 2025

Biological Importance and Management of Sound in the Sea

Marine animals make and receive sound for key life functions

- *Reproduction*
- *Foraging*
- *Predator Avoidance*
- *Spatial Orientation*

Humans also produce underwater sound - *intentionally* or *incidentally*

Applied Management Questions

- What human noise exposures negatively impact marine animals?
- How to establish and apply rules for managing impacts?
- What are appropriate (and legal) requirements for mitigation?
- How to keep up with science that is rapidly evolving?

Potential Effects of Noise on Marine Species

- None observable

- Interference with Communication
  - Auditory masking (loss of acoustic "habitat")
  - *Temporary* or permanent *hearing damage (TTS/PTS)*

- Behavioral Responses
  - Orientation, increased alertness, vocal changes
  - Effects on feeding, social activity, risk of predation
  - Habitat abandonment: temporary or *permanent*

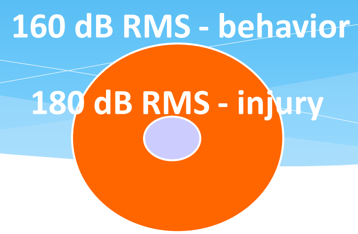
- Physiological Effects
- *Stranding causing injury or death*

Generally Increasing Severity

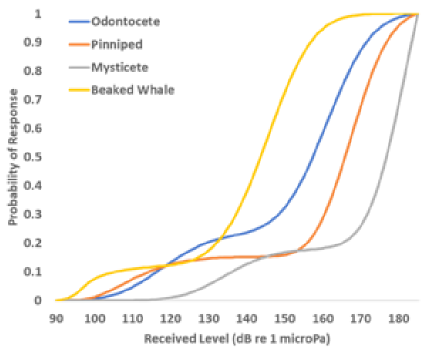
but

Generally Decreasing Occurrence

Evolving Methods for Evaluating Potential Effects of Noise



- **Threshold-based methods (step-functions)**



- **Probabilistic methods (risk functions)**

- **Analytical paradigms/frameworks**
  - ***Energetic and/or survival models for population-level effects***
  - ***Risk assessment methods: species, contextual, other factors***

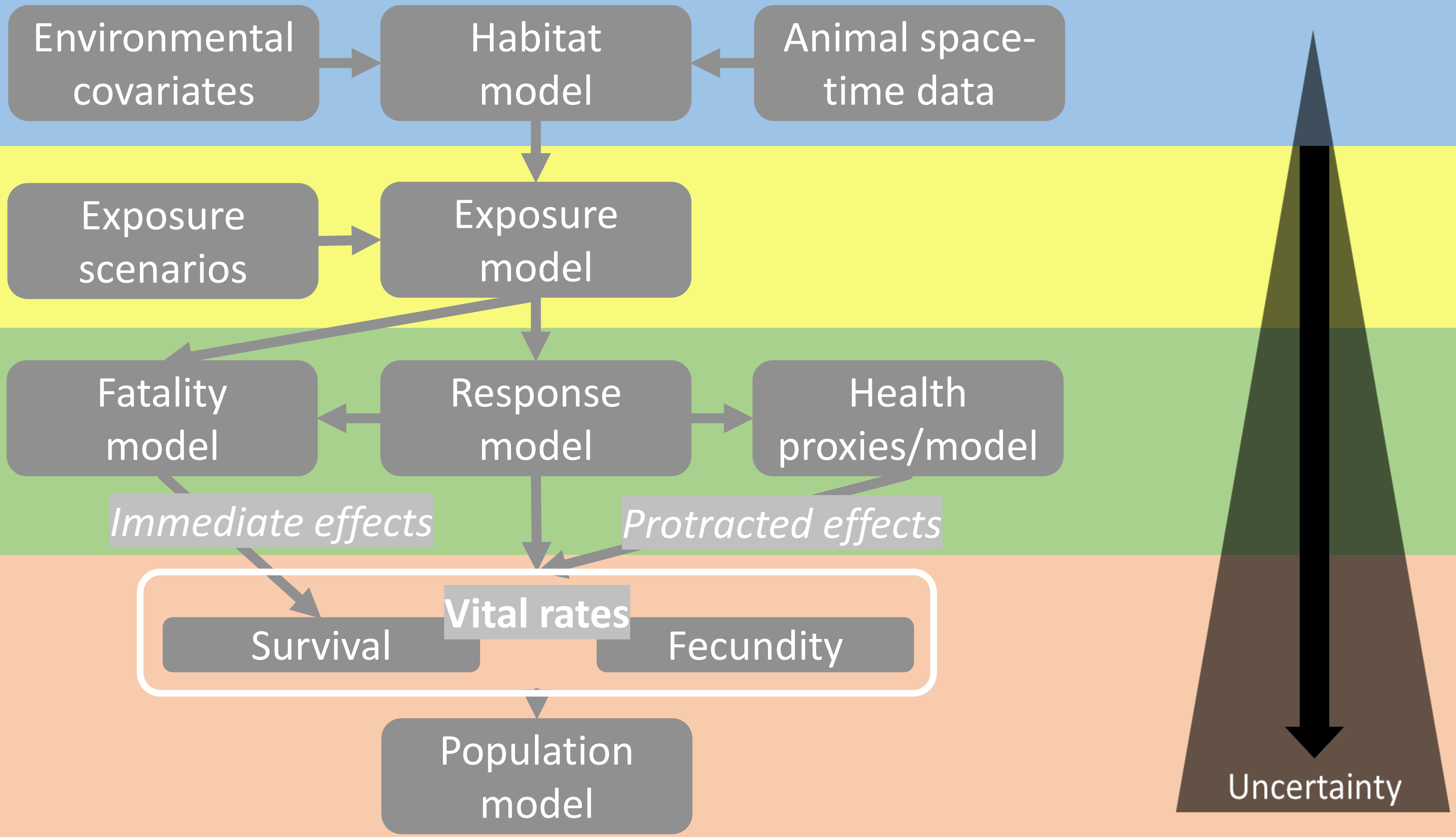
If we had perfect data & knowledge…

Occurrence
where, when, how long, how many animals ***use*** *sites/spaces*

Exposure
where, when, and how long animals are exposed

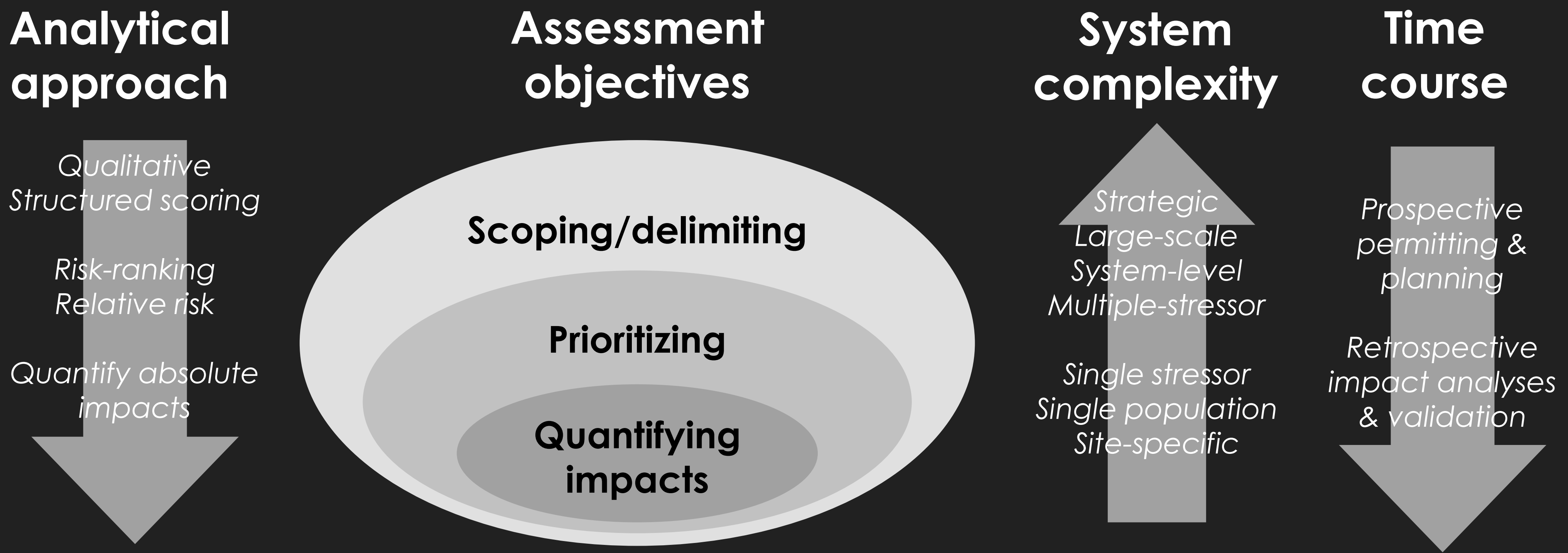
Response
likelihood & magnitude of individual-level effects

Consequence
likelihood & magnitude of population-level impacts



The need for simplified approaches to aid decision-making

- Insufficient or highly uncertain data/knowledge to construct & parameterize complex models
- Principle of parsimony to address a question
- Ultimately, pressure to expand marine renewables at pace, while having a process that assures of good stewardship



Risk Assessment Framework Overall Paradigm

Southall et al (2023)
Managing human activity and marine mammals: A biologically based, relativistic risk assessment framework

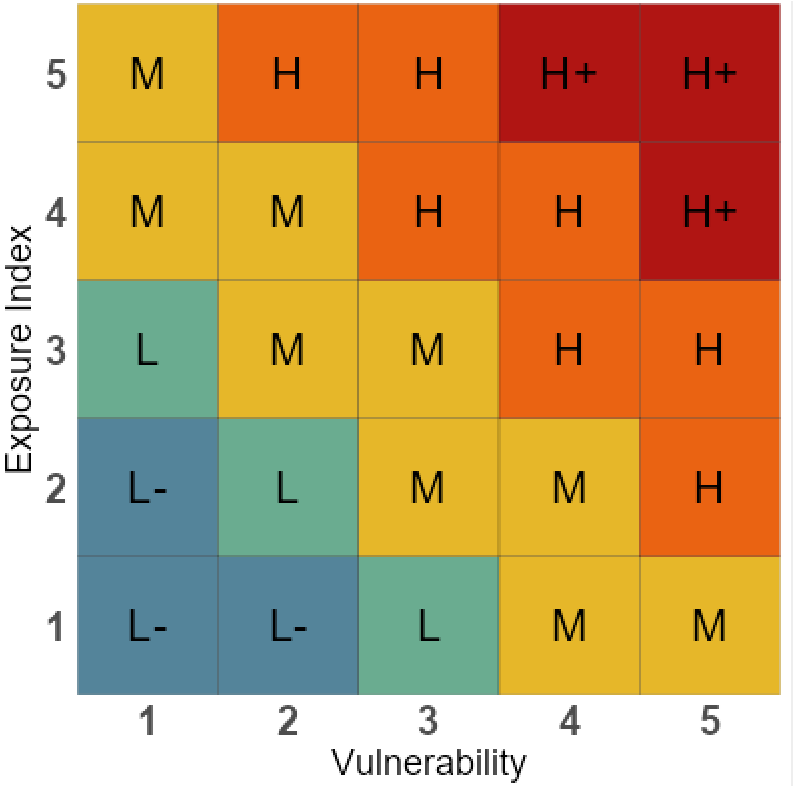
Brandon L. Southall[1,2*], Dominic Tollit[3], Jennifer Amaral[4], Christopher W. Clark[4,5] and William T. Ellison[4]

Relative Exposure Index: "Severity"

SPATIAL

TEMPORAL

SPECTRAL



Species and Context-Specific "Vulnerability"

Species Population Factor

Species Habitat Use, Compensatory Ability

Potential Masking Factor*

4. Other Environmental Stressors

Exposure Index Value (percentile values of % of zone population)	Exposure Index Relative Risk Rating
> 80th percentile	Highest (5)
> 60th to 80th percentile	Higher (4)
> 40th to 60th percentile	Moderate (3)
> 20th to 40th percentile	Lower (2)
< 20th percentile	Lowest (1)

Key	Color	Risk Assessment Rating
	Red	Highest (H+)
	Orange	Higher (H)
	Yellow	Moderate (M)
	Green	Lower (L)
	Blue	Lowest (L-)

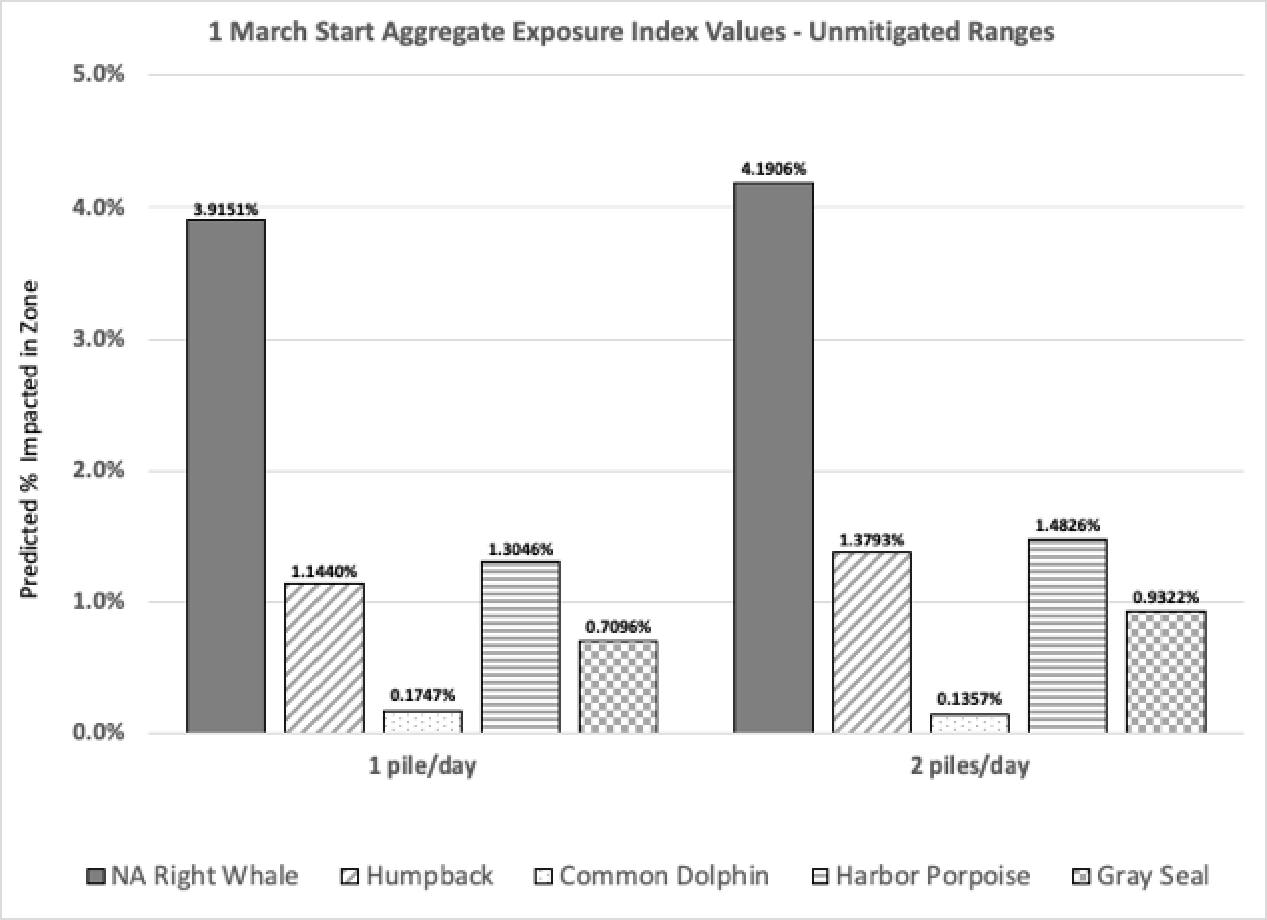
Total Vulnerability Score (from factors 1-4)	Total Risk Probability (% of total possible)	Relative Vulnerability Rating
24–30	80–100%	Highest
18–23	60–79%	High
12–17	40–59%	Moderate
6–11	20–39%	Low
0–5	0–19%	Lowest

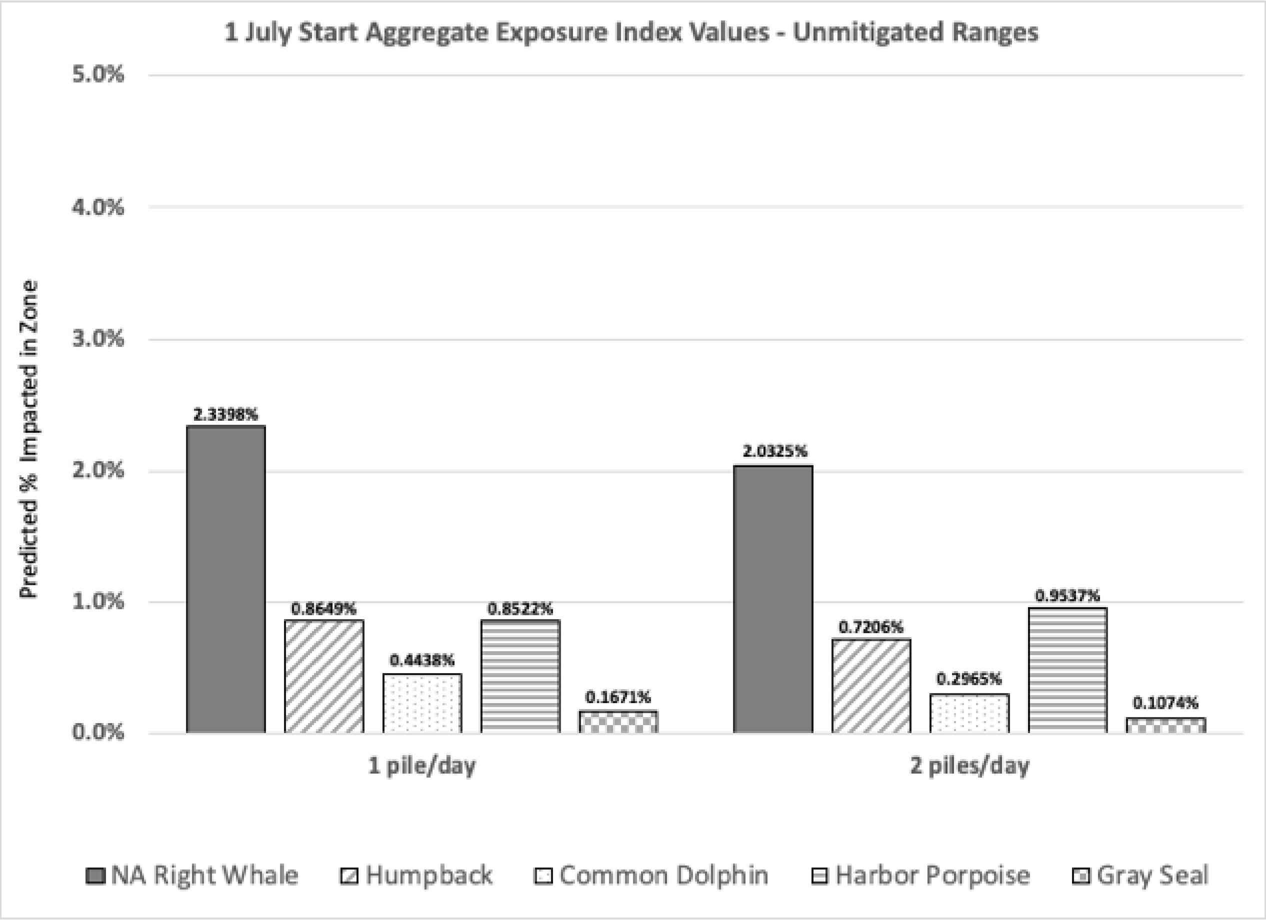
Example Results: Offshore windfarm installation

Managing human activity and marine mammals: A biologically based, relativistic risk assessment framework

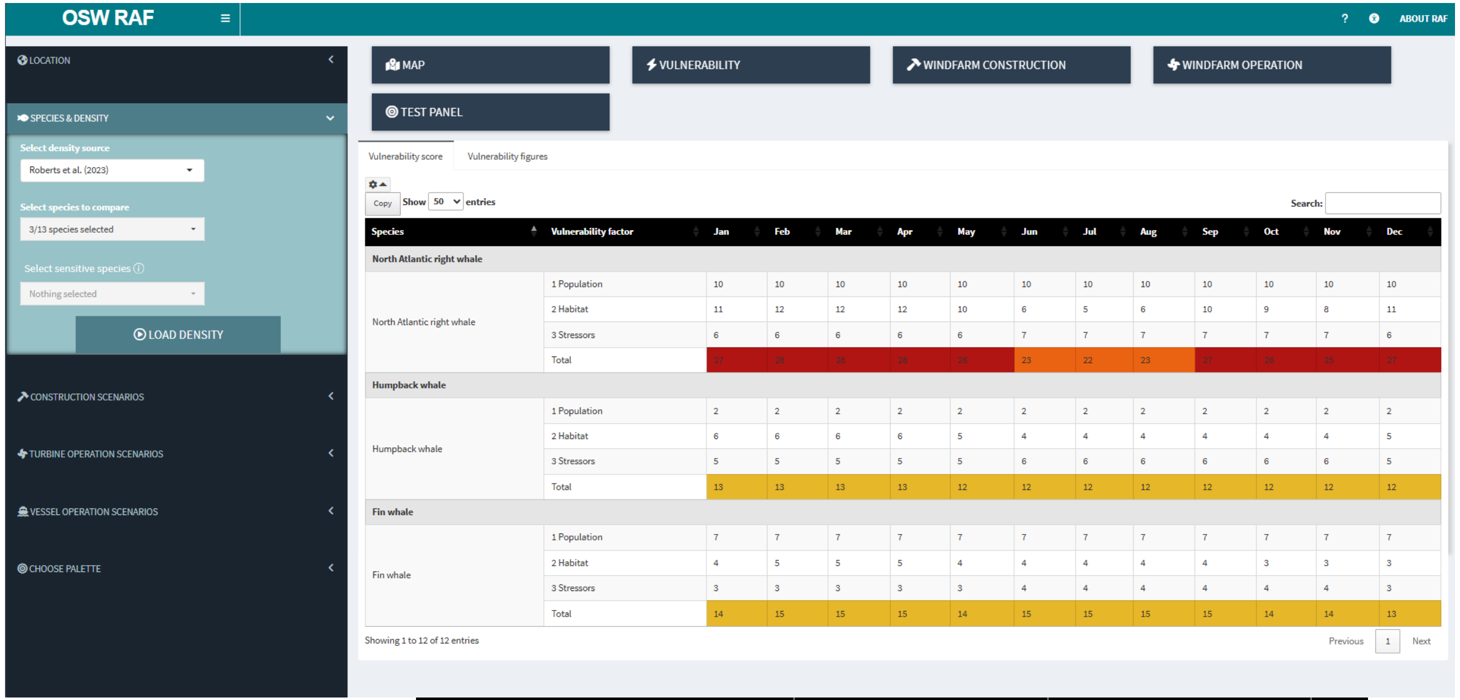
Brandon L. Southall[1,2*], Dominic Tollit[3], Jennifer Amaral[4], Christopher W. Clark[4,5] and William T. Ellison[4]

Aggregate Exposure Index - Year 1 scenario 1 March vs 1 July Start (unmitigated)





NEW R-SHINY RAF TOOL
Outputs and Visualizations for Selected Species



Species	Vulnerability factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Atlantic right whale													
North Atlantic right whale	1 Population	10	10	10	10	10	10	10	10	10	10	10	10
	2 Habitat	11	12	12	12	10	6	5	6	10	9	8	11
	3 Stressors	6	6	6	6	6	7	7	7	7	7	7	6
	Total	27	28	28	28	26	23	22	23	27	26	25	27
Humpback whale													
Humpback whale	1 Population	2	2	2	2	2	2	2	2	2	2	2	2
	2 Habitat	6	6	6	6	5	4	4	4	4	4	4	5
	3 Stressors	5	5	5	5	5	6	6	6	6	6	6	5
	Total	13	13	13	13	12	12	12	12	12	12	12	12
Fin whale													
Fin whale	1 Population	7	7	7	7	7	7	7	7	7	7	7	7
	2 Habitat	4	5	5	5	4	4	4	4	4	3	3	3
	3 Stressors	3	3	3	3	3	4	4	4	4	4	4	3
	Total	14	15	15	15	14	15	15	15	15	14	14	13

Showing 1 to 12 of 12 entries

Previous 1 Next

Scenario						Vulnerability index scores			Exposure index scores (%)				
scenario	n_turbines	Start date	Installation rate	Buffer size	Species	Aggregate vulnerability (monthly mean)	Aggregate vulnerability CV	Vulnerability rank	Aggregate EI (sum)	Aggregate EI (monthly mean)	Aggregate EI CV	EI rank	OVERALL RISK RANK
Common dolphin													
Scenario 1	120	2025-03-01	1	5	Common dolphin	8	0	2	0.0435	0.0109	0.2524	1	Lowest
Scenario 2	120	2025-05-01	1	5	Common dolphin	8	0	2	0.0603	0.0151	0.1745	2	Low
Scenario 3	120	2025-07-01	1	5	Common dolphin	8.5	0.0679	2	0.0841	0.021	0.3206	3	Moderate
North Atlantic right whale													
Scenario 1	120	2025-03-01	1	5	North Atlantic right whale	26.25	0.09	5	0.3774	0.0944	0.2892	5	Highest
Scenario 2	120	2025-05-01	1	5	North Atlantic right whale	23.5	0.0737	5	0.298	0.0745	0.3939	4	Highest
Scenario 3	120	2025-07-01	1	5	North Atlantic right whale	24.5	0.0972	5	0.3374	0.0843	0.3142	4	Highest

Showing 1 to 6 of 6 entries

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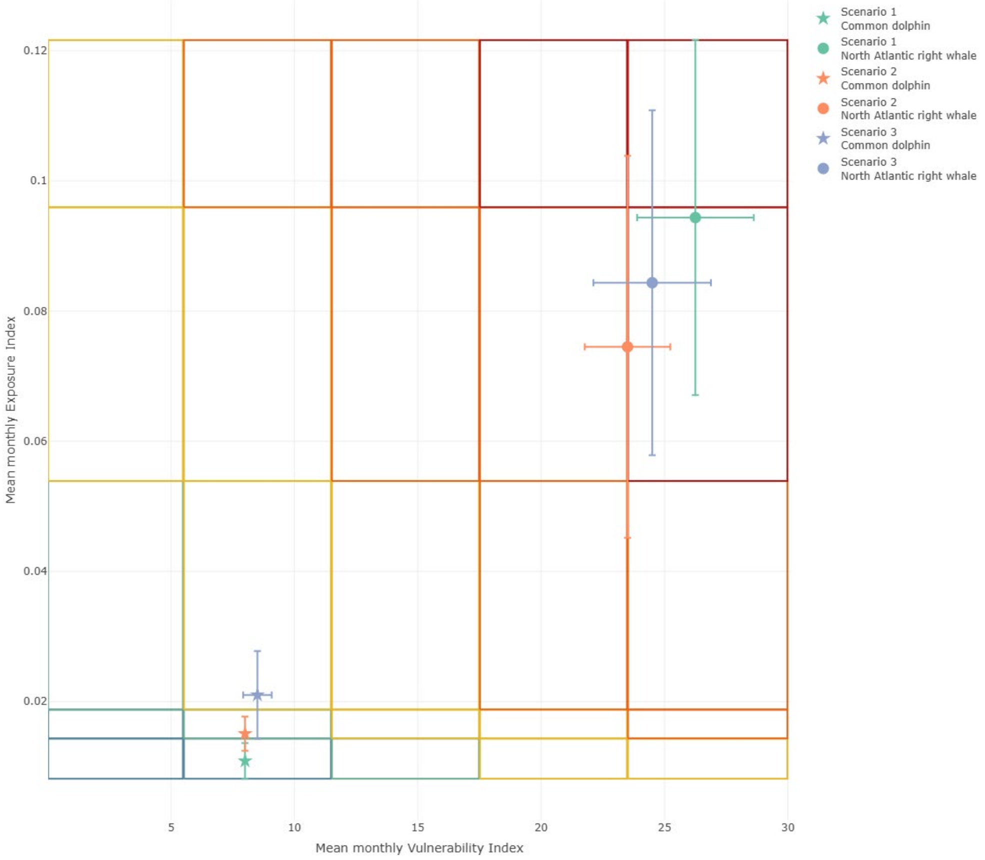


A spectrum of approaches to risk analysis

Mechanistic | **Empirical** | **Heuristic**

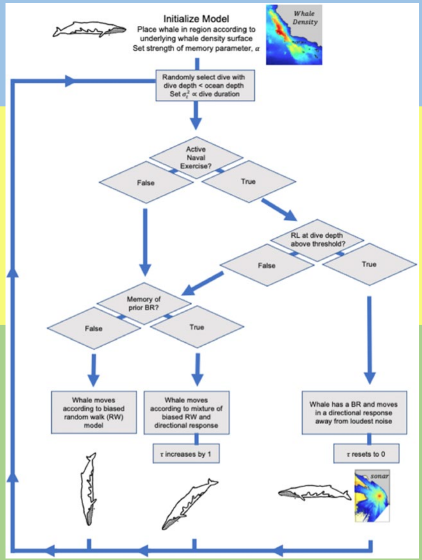
Occurrence
*where, when, and how long birds **use** sites/spaces*

Exposure
where, when, and how long birds are exposed

Response
likelihood & magnitude of individual-level effects

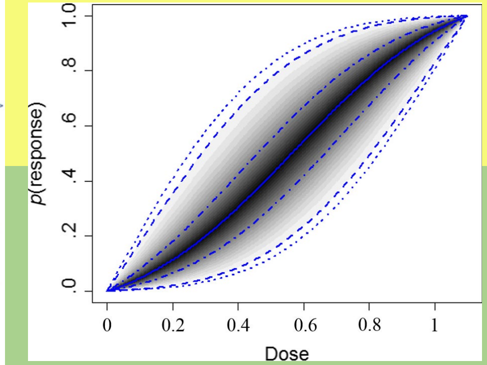
Consequence
likelihood & magnitude of population-level impacts

Individual-based models (IBMs) of movement

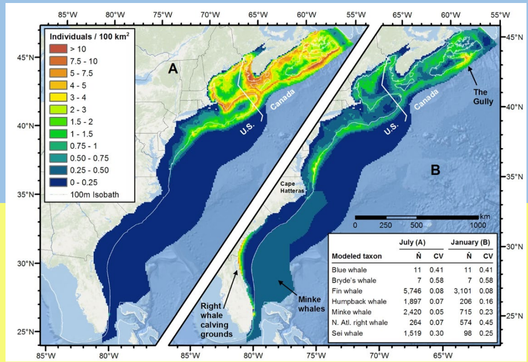


Joy et al 2022

Species distribution & habitat modelling, species niche & richness modelling



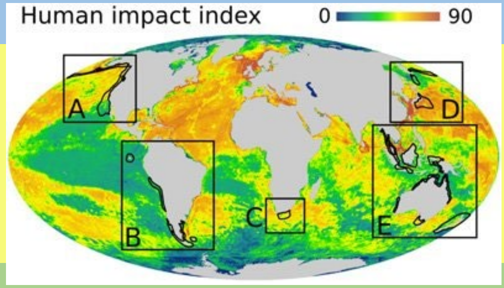
Harris et al 2017



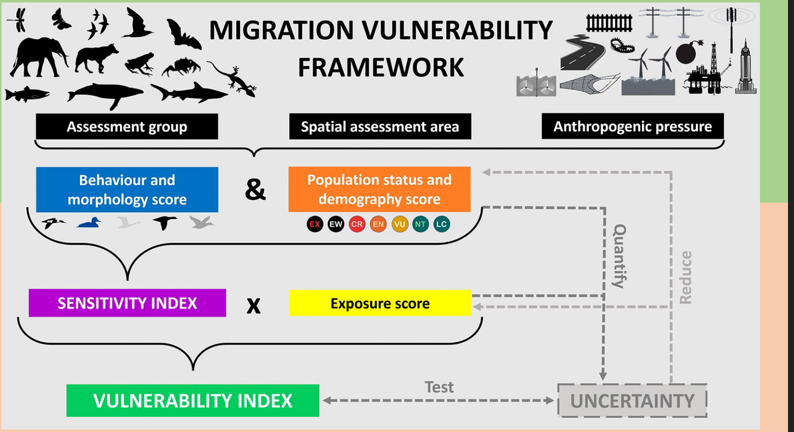
Roberts et al 2016

Behaviour response studies (BRS), controlled exposure experiments (CEEs)

Structured scoring (or "weight-of-evidence") algorithms, sensitivity mapping / spatial prioritization tools



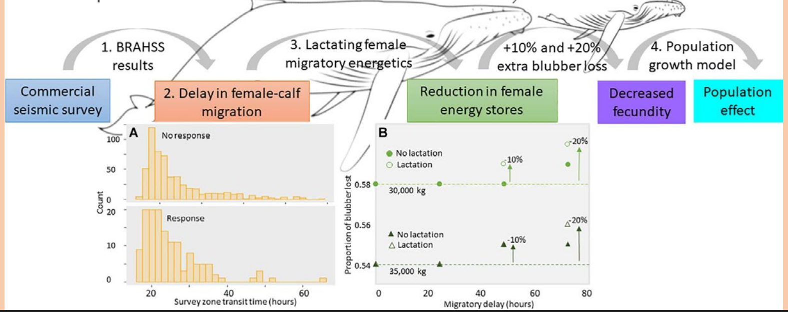
Davidson et al 2012



Green et al 2025

Population-Consequence of Disturbance Models (PCoD), population viability analyses (PVA)

Dunlop et al 2021



Potential Biological Removal (PBR) Wade et al 1998

Comprehensive assessment example: Grace Edmondson PhD project

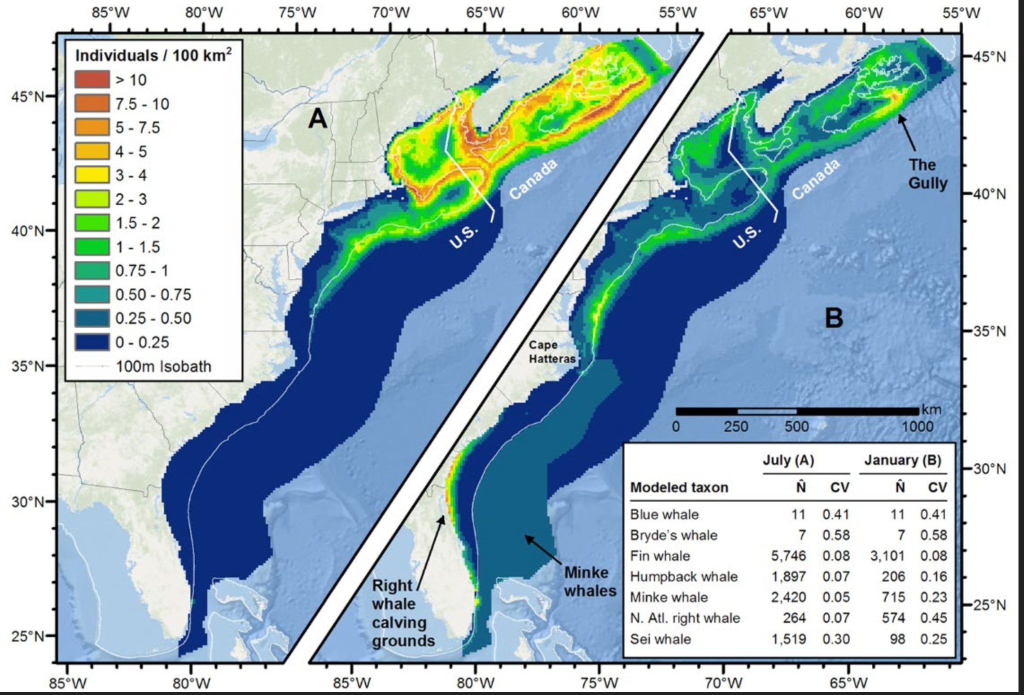
Occurrence
*where, when, and how long cetaceans **use** sites/spaces*

Environmental covariates → Habitat model ← Animal space-time data

Individual usage: generate individual movements from estimated monthly density distributions (Roberts et al 2016)

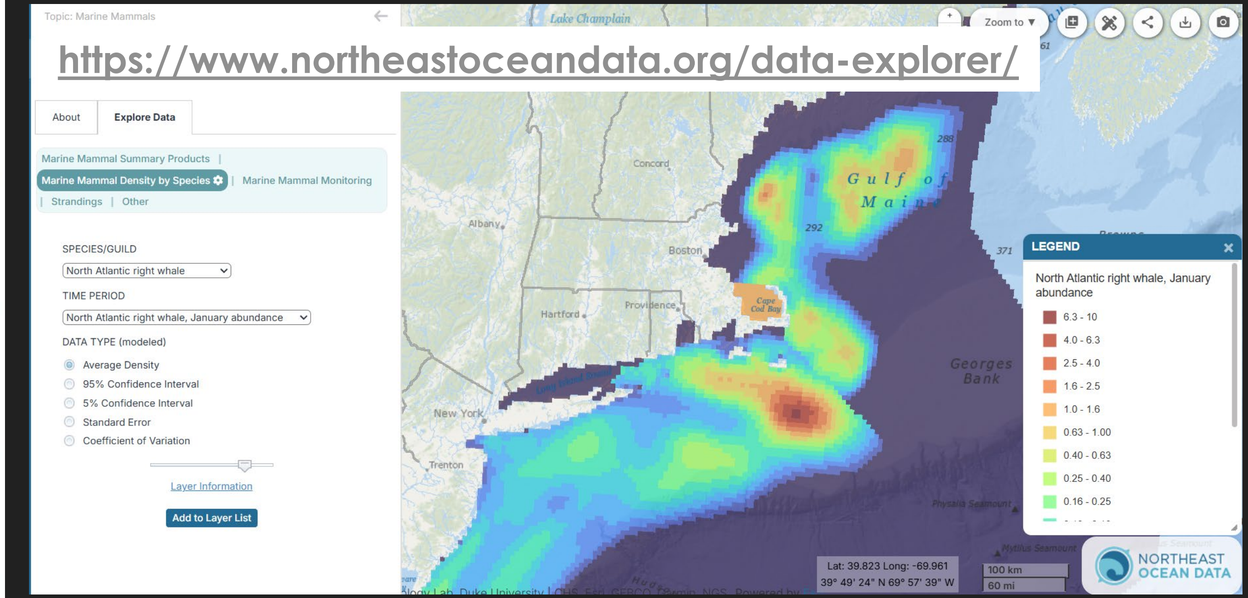
Figure 5: Predicted mean density of baleen whales in July (A) and January (B) for the East Coast region.

From: Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico



Modeled taxon	July (A) N̂	July (A) CV	January (B) N̂	January (B) CV
Blue whale	11	0.41	11	0.41
Bryde's whale	7	0.58	7	0.58
Fin whale	5,746	0.08	3,101	0.08
Humpback whale	1,897	0.07	206	0.16
Minke whale	2,420	0.05	715	0.23
N. Atl. right whale	264	0.07	574	0.45
Sei whale	1,519	0.30	98	0.25

https://www.northeastoceandata.org/data-explorer/



OPEN

Habitat-based cetacean density models for the U.S. Atlantic and Gulf of Mexico

Received: 18 November 2015
Accepted: 17 February 2016
Published: 03 March 2016

Jason J. Roberts[1], Benjamin D. Best[1,2], Laura Mannocci[1], Ei Fujioka[1], Patrick N. Halpin[1], Debra L. Palka[3], Lance P. Garrison[4], Keith D. Mullin[5], Timothy V. N. Cole[3], Christin B. Khan[3], William A. McLellan[6], D. Ann Pabst[6] & Gwen G. Lockhart[7]

Marine Geospatial Ecology Lab • Duke University

Comprehensive assessment example: Grace Edmondson PhD project

Occurrence

*where, when, and how long cetaceans **use** sites/spaces*

Environmental covariates → Habitat model ← Animal space-time data

Habitat model ↓ Exposure model

Exposure

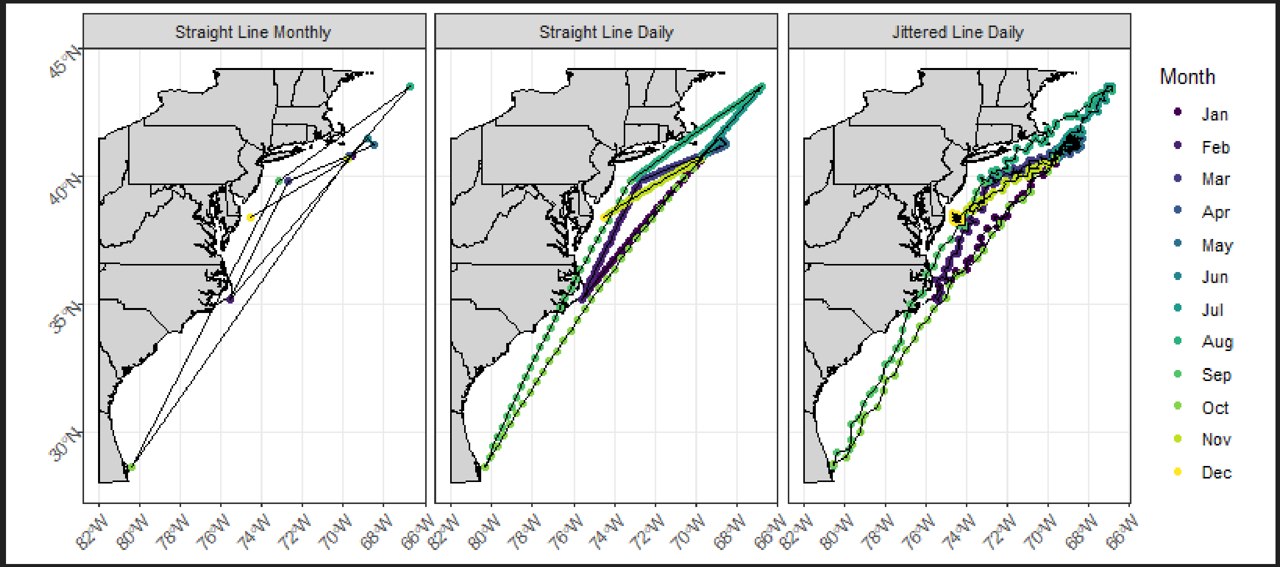
where, when, and how long cetaceans are exposed

Exposure scenarios → Exposure model

Individual usage: generate individual movements from estimated monthly density distributions (Roberts et al 2016)

Exposure scenario: combine planned turbine installations with a propagation model, calculate RL at individual locations

Aggregate exposure estimation



$$Propoagation\ Loss = Spreading\ Loss + Absorption\ Loss$$
$$= \omega\ log_{10}(r) + \alpha \times r$$

Spreading loss: ω determines the shape of spreading loss; ω = 20 when r is less than water depth and ω = 17 when r is greater than water depth

Absorption loss:

$$\alpha = 0.106 \times \frac{f_1 \times f^2}{f^2 + f_1^2} \times e^{\frac{(pH-8)}{0.56}} + 0.52 \times \left(1 + \frac{t}{43}\right) \times \frac{s}{35} \times \frac{f_2 \times f^2}{f^2 + f_2^2} \times e^{\frac{-z}{6}} + 0.00049 \times f^2 \times e^{-\left(\frac{t}{27} + \frac{z}{17}\right)},$$

where pH = 7.98, s (salinity) = 33.12ppt, t (temperature) = 12.19 °C, z (depth) = 36.43km and frequency we use the third octave bands in the piling spectrum.

Comprehensive assessment example: Grace Edmondson PhD project

Occurrence
*where, when, and how long cetaceans **use** sites/spaces*

Environmental covariates → Habitat model ← Animal space-time data

Individual usage: generate individual movements from estimated monthly density distributions (Roberts et al 2016)

Exposure
where, when, and how long cetaceans are exposed

Habitat model → Exposure model

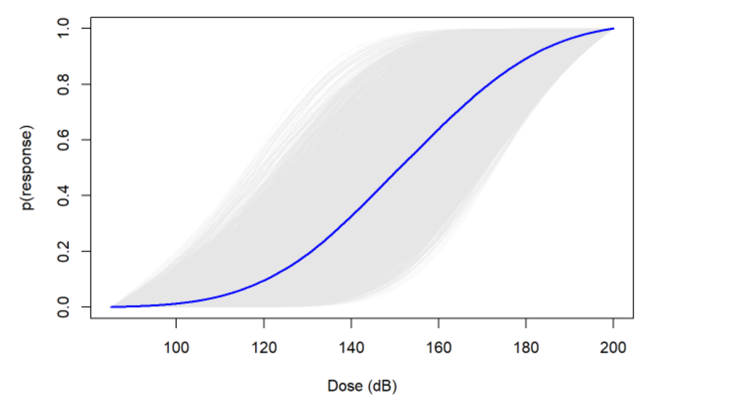
Exposure scenarios → Exposure model

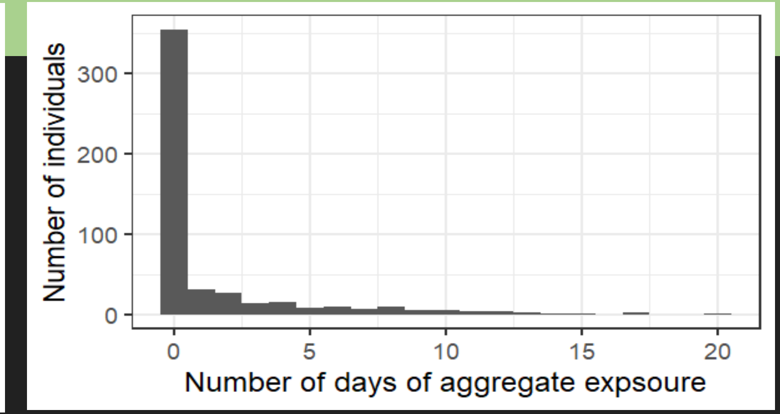
Exposure scenario: combine planned turbine installations with a propagation model, calculate RL at individual locations

Response
likelihood & magnitude of individual-level effects

Exposure model → Response model

Aggregate response: dose-response framework to estimate P(response) each day, then aggregate number of days each individual is disturbed





Comprehensive assessment example: Grace Edmondson PhD project

Protracted effects

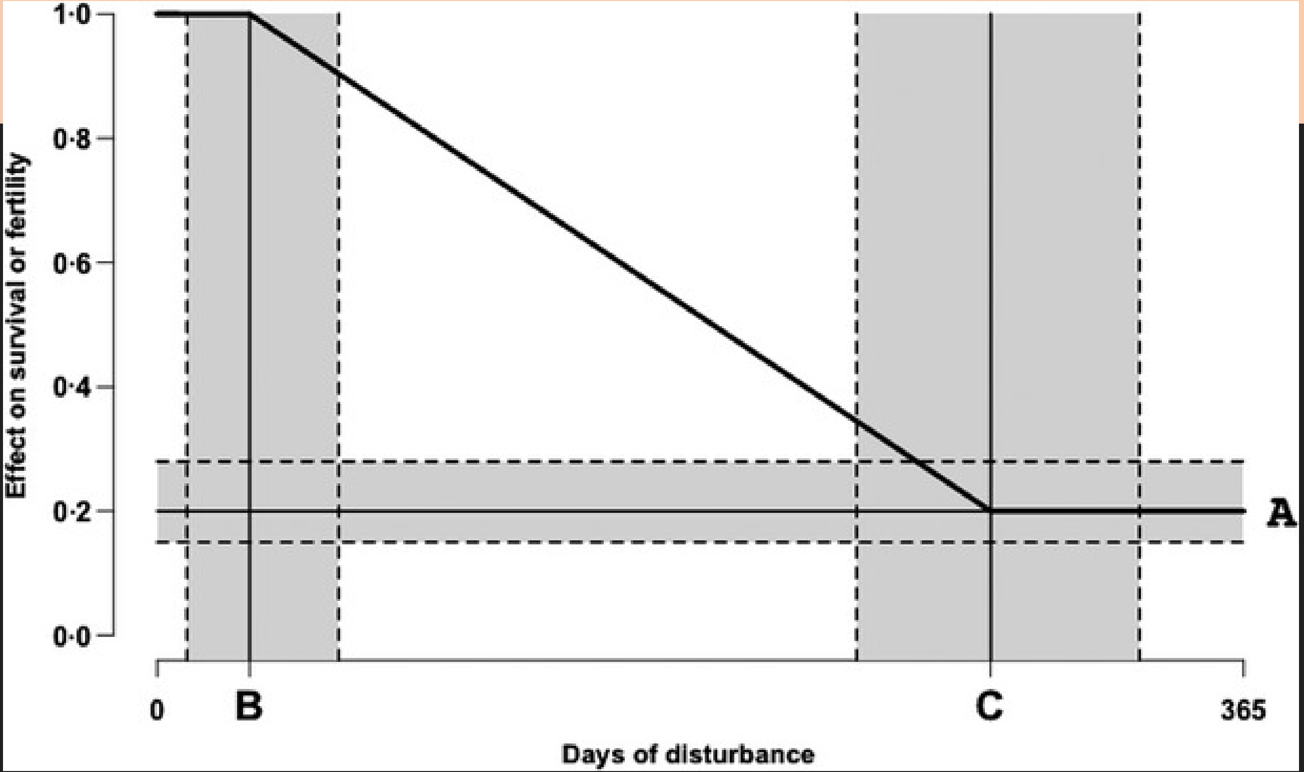
Consequence

likelihood & magnitude of population-level impacts

Vital rates

Survival

Fecundity



Population consequence (iPCoD): convert number of disturbance days to reduced survival/fecundity using an expert-elicited function (King et al 2021)

Methods in Ecology and Evolution

Methods in Ecology and Evolution 2015, 6, 1150–1158 doi: 10.1111/2041-210X.12411

An interim framework for assessing the population consequences of disturbance

Stephanie L. King[1,2], Robert S. Schick[2], Carl Donovan[3], Cormac G. Booth[1], Mark Burgman[4], Len Thomas[2] and John Harwood[1,2*]

Comprehensive assessment example: Grace Edmondson PhD project

Protracted effects

Consequence

likelihood & magnitude of population-level impacts

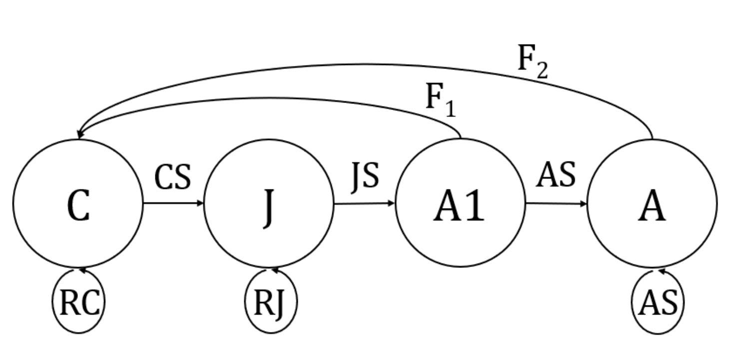
Vital rates

Survival

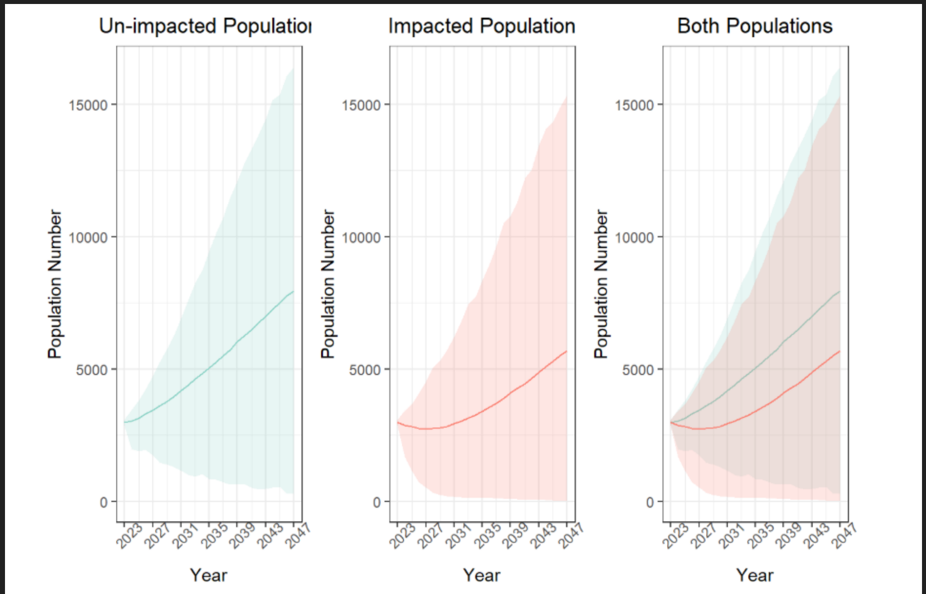
Fecundity

Population model

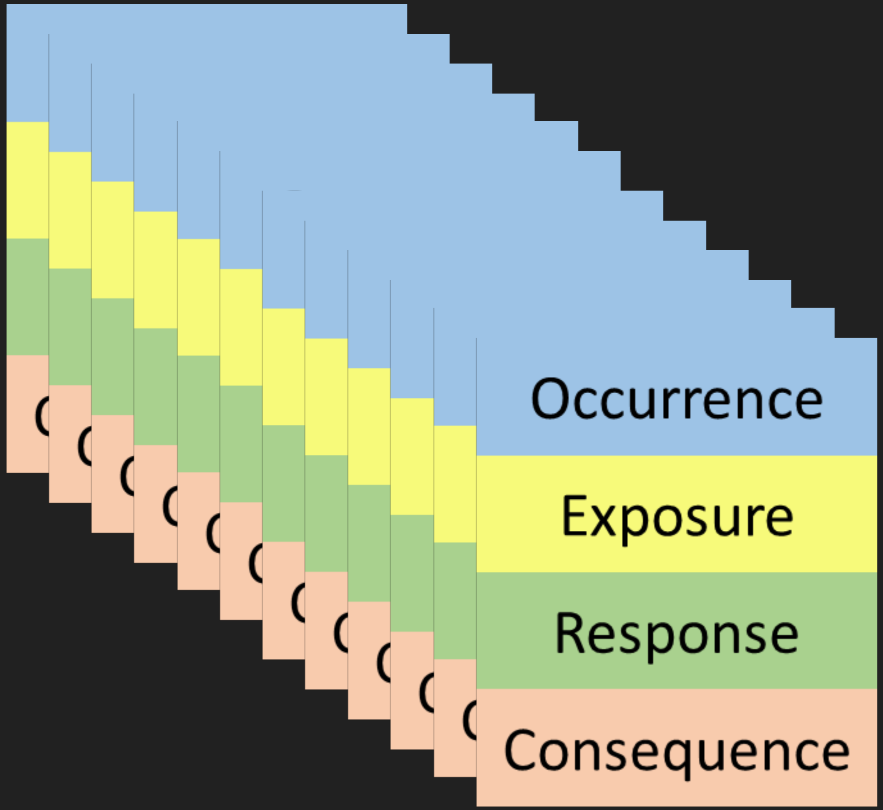
Population consequence (iPCoD): convert number of disturbance days to reduced survival/fecundity using an expert-elicited function (King et al 2021), stage-structured population models to project potential consequences in future

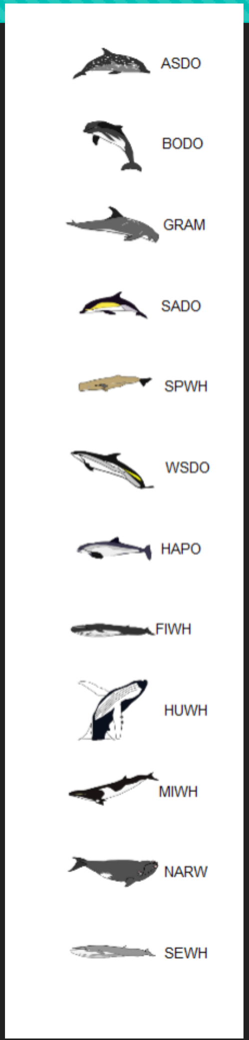


$$\begin{bmatrix} RC & 0 & F_1 & F_2 \\ CS & RJ & 0 & 0 \\ 0 & JS & 0 & 0 \\ 0 & 0 & AS & AS \end{bmatrix}$$

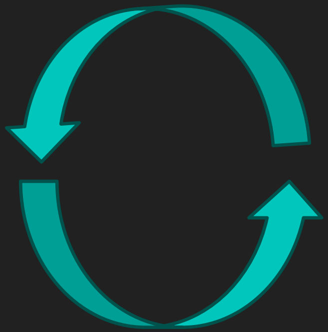


Repeat for 12 species, rank, compare

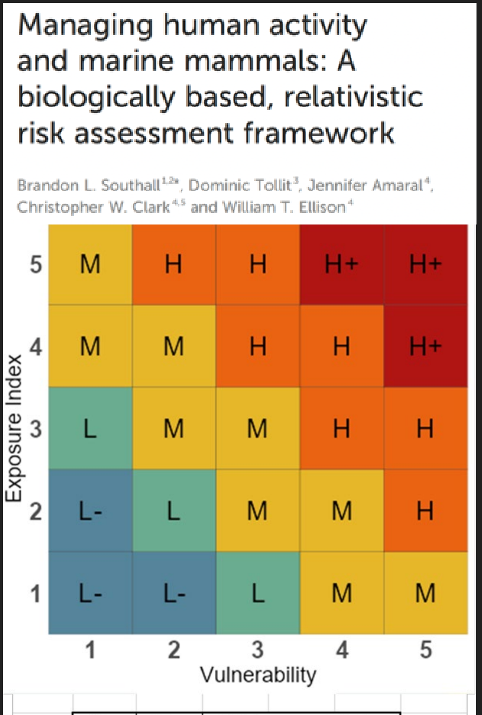




Cross-validation:
Rank species & exposure scenarios, then compare with structured scoring approach



Southall et al (2023)



Key	Color	Risk Assessment Rating
	Red	Highest (H+)
	Orange	Higher (H)
	Yellow	Moderate (M)
	Green	Lower (L)
	Blue	Lowest (L-)

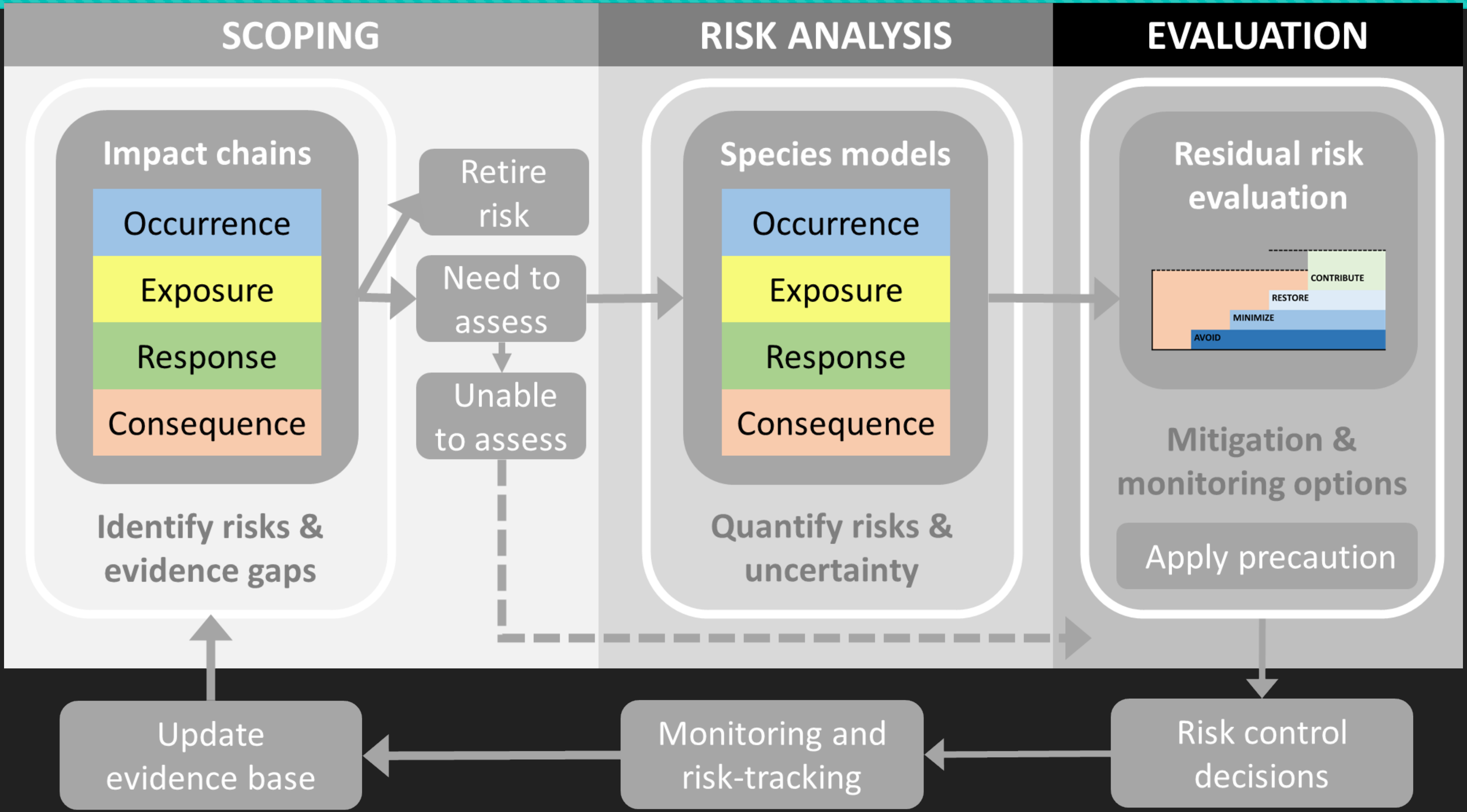
Risk analyses in data-poor contexts

Approaches

1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty in data & models

1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty

Scoping vs full risk analysis



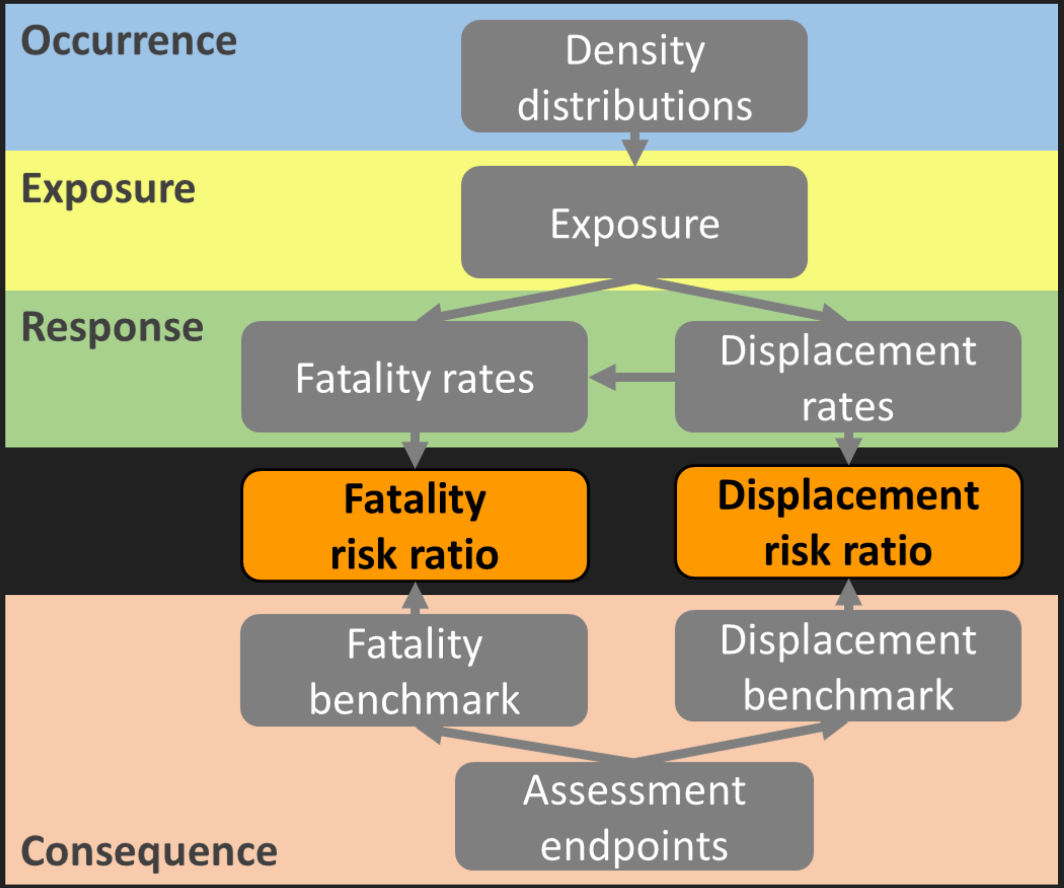
1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty

Relative risk vs risk-ranking

- **Risk** = the likelihood and consequence of outcomes for species/populations
- **Relative species risk** = risks benchmarked against assessment targets. *Can inform about magnitude differences in risk. For example:*

Risk ratio = **Expected level of risk** / **Allowable level of risk**

- **Risk ranking =** rank order of species, scenarios or locations (sensitivity maps) by relative risk. *Cannot inform about magnitude differences – but less demanding of data & benchmarks.*



1. Adjust objectives
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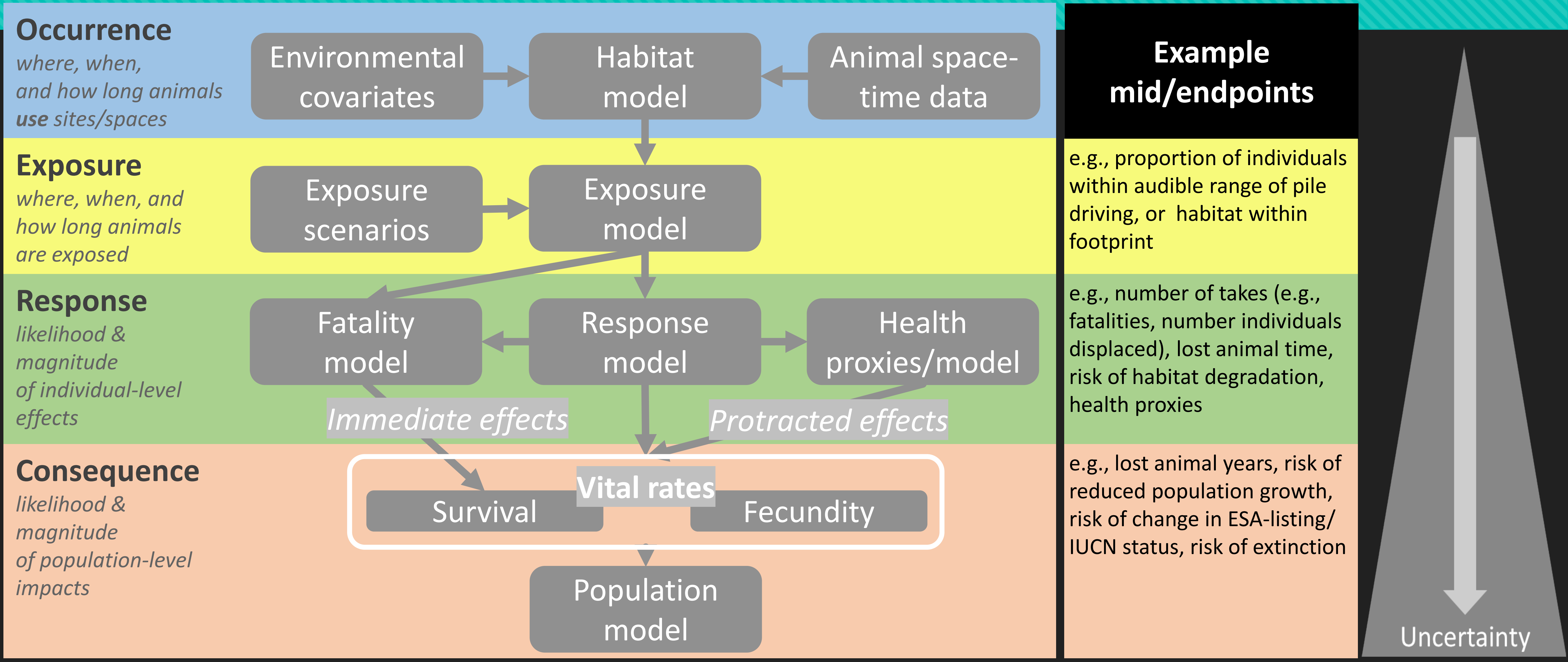
Assessment endpoints



1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty

Pooling/grouping

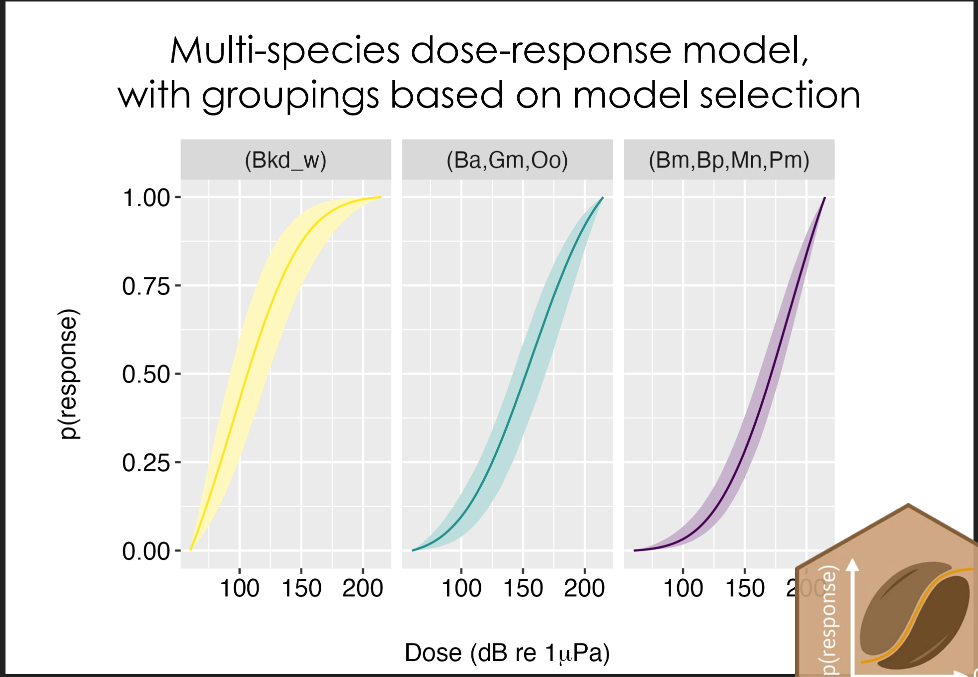
Groupings based on hearing alone…

Marine Mammal Hearing Groups (NMFS 2018)

Hearing Group	Generalized Hearing Range*
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, Cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

* Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).

… vs groupings based on responsiveness



https://pjbouchet.github.io/espresso/

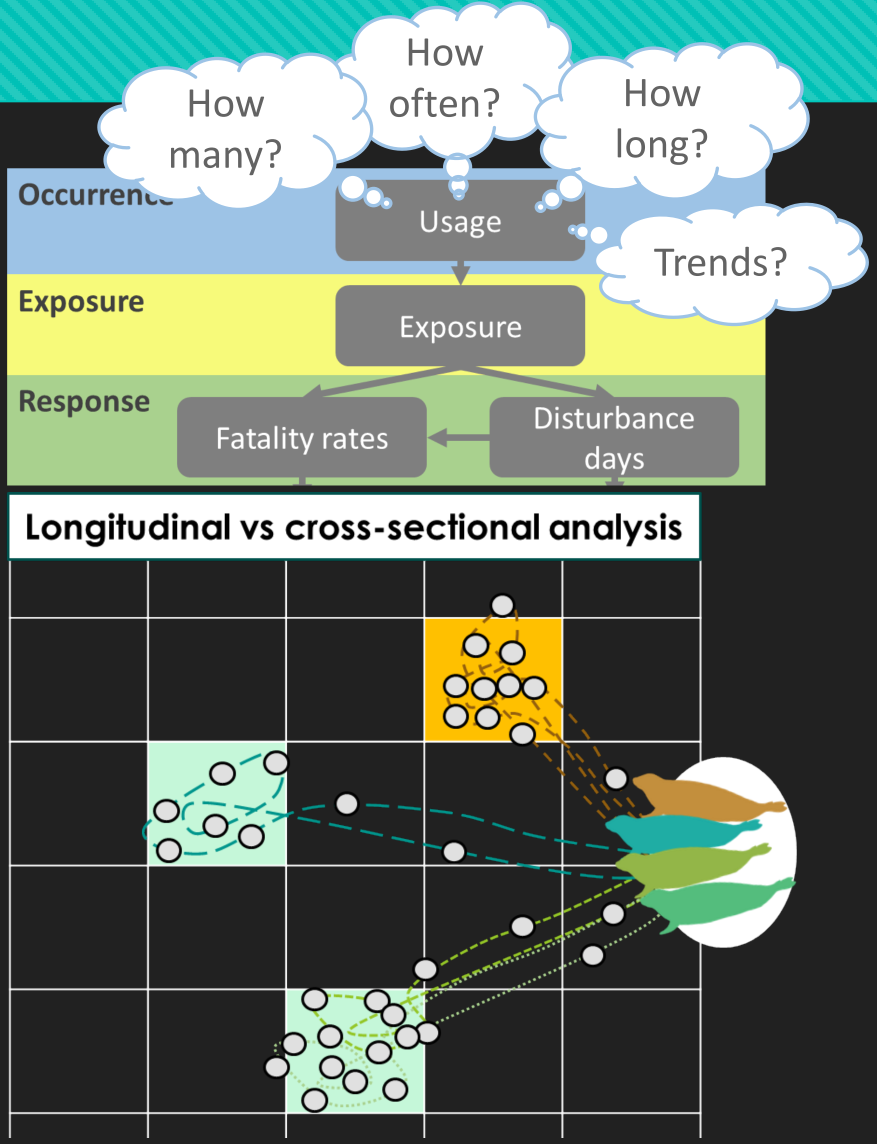
Trait-based assessment when species-specific data are scarce (Baird et al 2008, Thaxter et al 2017, Galic et al 2024)

1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty

Proxies for usage

- When no usage data available: umbrella/proxy species, adjust resolution
- Density distributions as proxy for average usage and exposure
    - *Many individuals disturbed a little, or few animals a lot?*
    - *Assumes perfectly mixed and homogenous population*
    - *Under-represents important movement routes*

Need tools to estimate **aggregate** usage and exposure → aggregate effects on individuals



1. Adjust objectives
2. Pool input data/parameters
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4. Simplify models (impact pathways)
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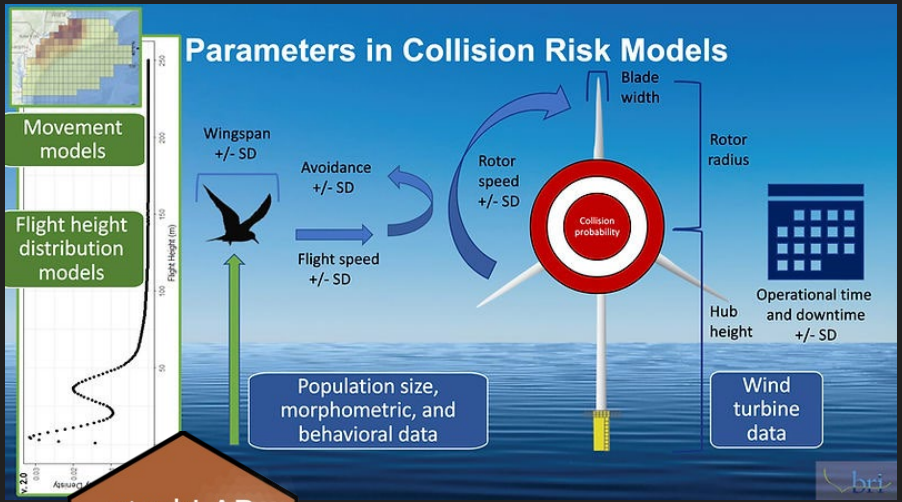
Simplifying impact pathways

(mechanistic models can be simple, too!)

Mechanistic, absolute risk — **Simplified, mechanistic index** — **Heuristic score**



stochLAB

https://hidef-aerial-surveying.github.io/stochLAB/

https://dmpstats.shinyapps.io/avian_stochcrm/

entering wind farm, after macroavoidance

Proportion time flying during day vs night

Proportion of flights at rotor height

Proportion of time with blade at path ~ f(flight speed)

P(collision | microavoidance) ~ f(manoeuvrability, day-night)

Flight altitude score × OR + (Flight time score + Nocturnal flight activity + Manoeuvrability score)

Fauchald et al 2023, Kelsey et al 2018:

The indicator for collision risk (*VC*) was defined by four variables: (1) Nocturnal flight activity (*d*), (2) Proportion of time flying (*e*), (3) Proportion of time spent at rotor height (*f*), and (4) Flight maneuverability (*g*):

$$VC = \frac{(d+e)/2 + f + g}{3} \quad (4)$$

Furness et al 2013:

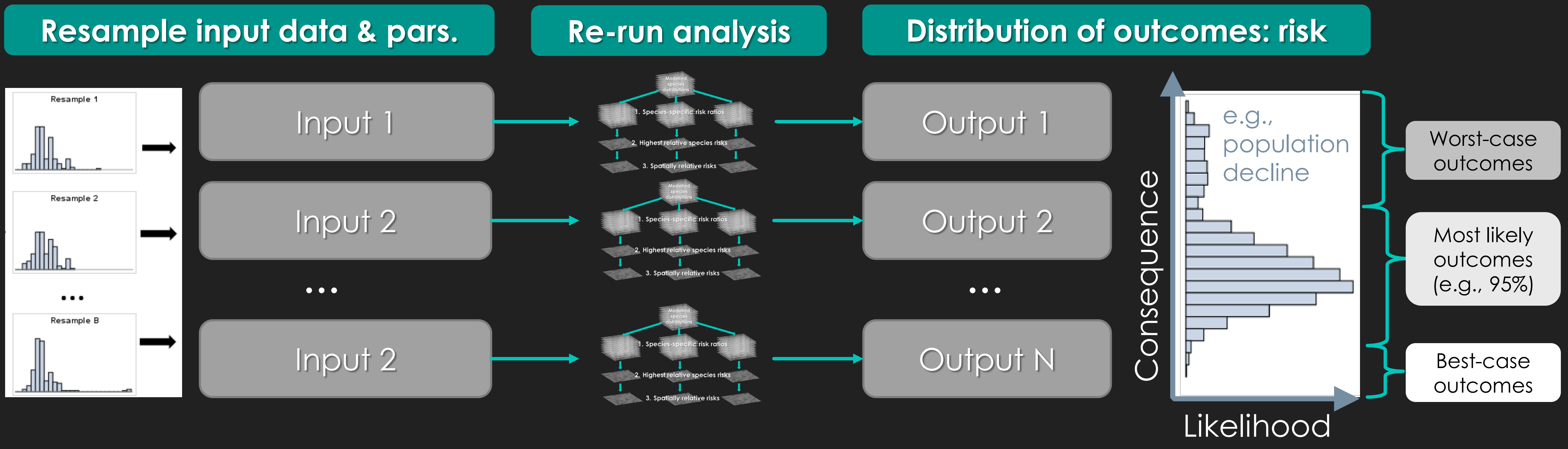
We use an alternative approach and score separately for collision concern and for disturbance/habitat displacement concern. For collision risk, we give a high weighting to flight altitude (*e*), and lower weighting to manoeuvrability (*f*), percentage of time flying (*g*), and nocturnal flight activity (*h*) (Equation (2)).

$$\text{Collision risk score} = e \times (f+g+h)/3 \times \text{conservation importance score} \quad (2)$$

Collision risk model (CRM), n_p=9 | A simple mechanistic index, n_p=5 | Collision risk score, n_p=4

1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty

Uncertainty propagation



Recap & recommendations

Approaches

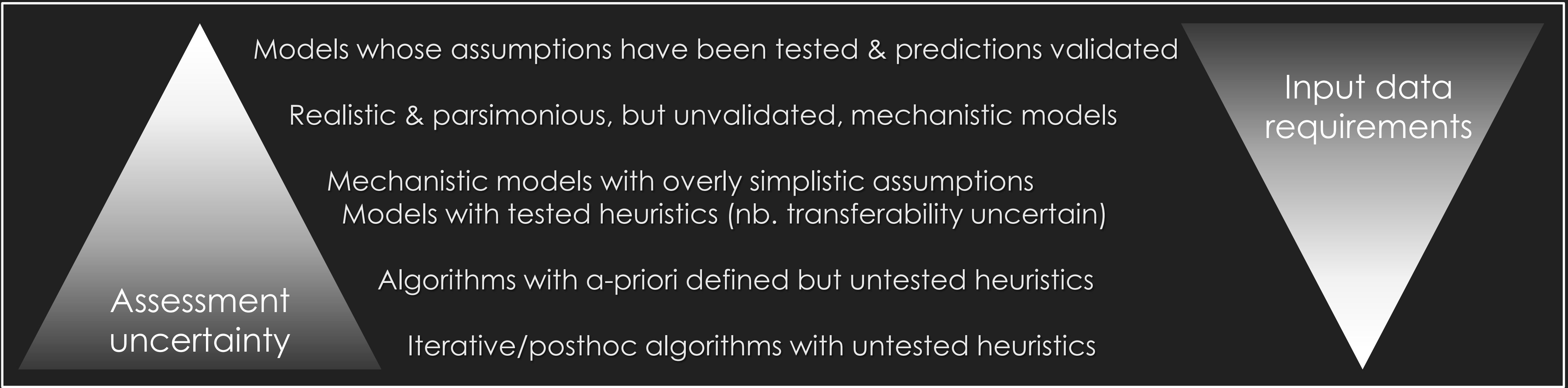
1. Adjust objectives
2. Pool input data/parameters
3. Use proxies
4. Simplify models (impact pathways)
5. Quantify uncertainty in data & models

Ideally using:

- Clearly defined assessment endpoints
- Evidence-based pooling
- Evidence-based, validated proxies
- Causal pathways of impact
- Uncertainty propagation, sensitivity analysis

Final thoughts & future directions

- Within the spectrum of available approaches, there is a hierarchy of preferable options:



- Whichever the approach, need to consider both parameter and model uncertainty.
- Going forward, more cross-validation of different approaches needed.

CREEM

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Thank you!

Questions or comments?

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