Collision risk to marine animals (fish) from tidal turbines: next steps towards understanding and retiring risk

March 16, 2021

7:30 – 10:30am Pacific Time

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Agenda

Introduction & goal of the workshop

Introduction to collision risk & encounter risk models

Background presentation on fish

Instructions and goals for the breakout sessions

First breakout session and report out

Quick Break ~ 16:05-16:15 UTC (9:05-9:15 PDT)

How models have been used so far

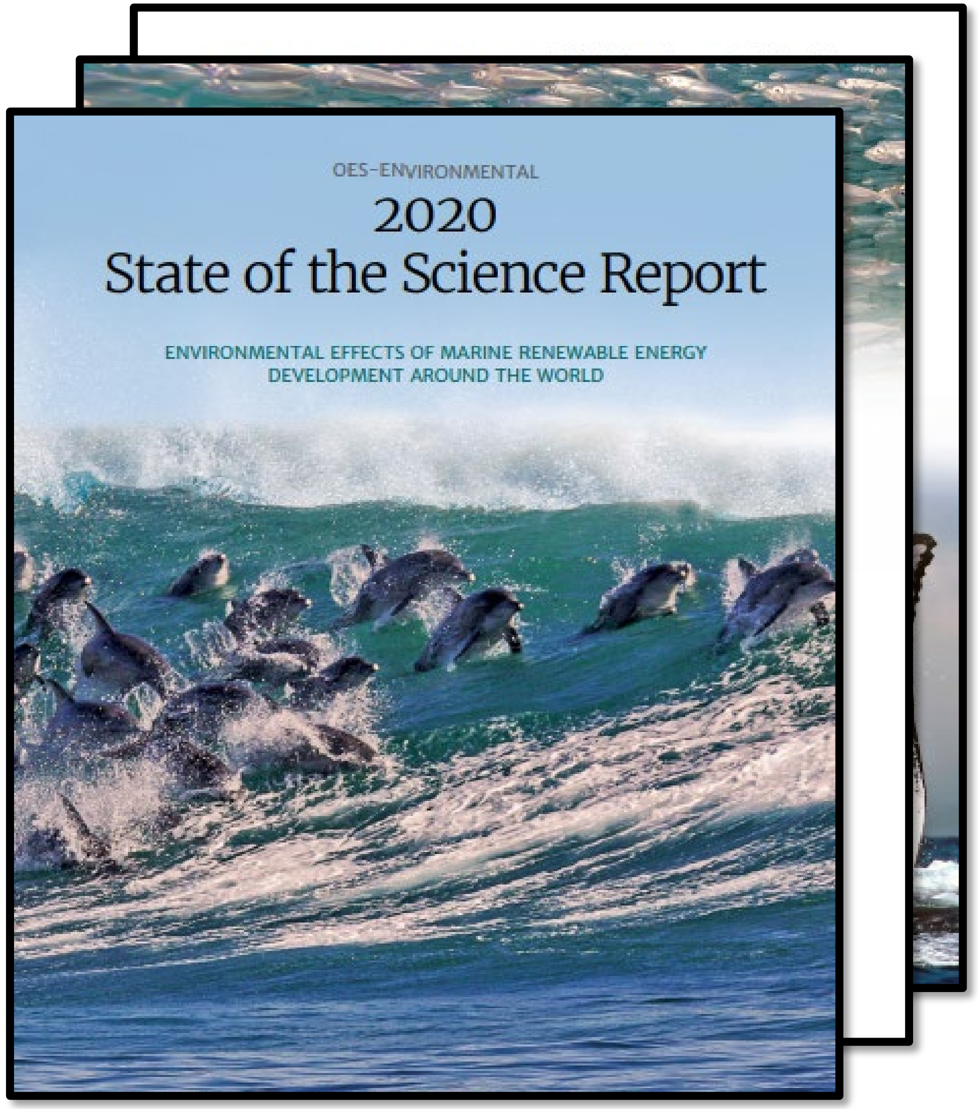
Second breakout session and report out

Open discussion of collision risk progress

Wrap up

OES-Environmental

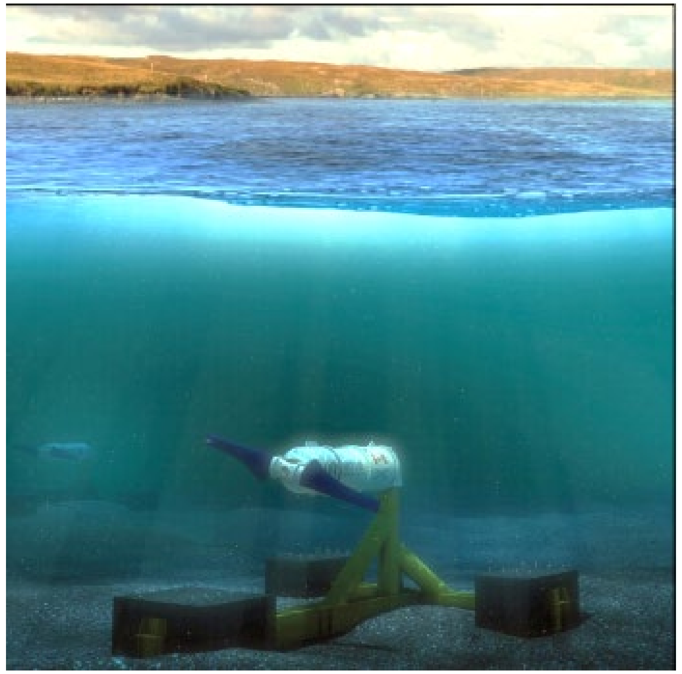
- Established by the International Energy Agency (IEA) Ocean Energy Systems (OES)
- Led by the U.S. Department of Energy's Pacific Northwest National Laboratory
- 15 countries currently involved
- Examines the environmental effects of MRE
- Activities coordinated and recorded on *Tethys* (*https://tethys.pnnl.gov/*)



OES ENVIRONMENTAL TETHYS

ORJIP Ocean Energy

- UK funded programme
- The aim is to reducing consenting risks for wave, tidal stream and tidal range projects.
- Facilitates a strategic, coordinated and prioritised approach to monitoring and research which is endorsed by industry, regulators and SNCBs.
- Key outputs:
  - Forward Look
  - Critical Evidence Gaps of wave and tidal energy
- Join our network to hear more by emailing ORJIP@aquatera.co.uk



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Goal of the Workshop

- How can models help us understand collision risk between marine animals and turbines, and facilitate consenting/permitting requirements?
  - Highlight knowledge and data gaps limiting our understanding of collision risks
  - Identify methods for collecting the necessary data
  - Determine the suitability of models to assess collision risk and population effects
  - Identify the data needs for parameterizing and validating the models
- Leverage participants' interests and expertise to trigger international collaborations

Introduction to Collision Risk Models

Lysel Garavelli, PhD

Pacific Northwest National Laboratory

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Some definitions

- **Avoidance**: Animal responding to and moving away from a device at great distances
- **Evasion**: Animal changing its behavior to escape a contact with a device at close distance (after the encounter, but adverting the collision)

Some definitions

- **Encounter**: Animal being in the nearfield of a turbine (1-5 devices length)
- **Collision**: Animal being in contact with the blade of a turbine
- **Exposure Time**: Amount of time animal spends at the depth and in the field of a device.

What do we use collision risk models for?

- **Purpose**:
  - To estimate the likelihood of an **encounter** between an animal and a device
  - To estimate the likelihood of **contact (collision)** between an animal and a device

- **Rates of encounter/collision depend on**:
  - Size and location of the device
  - Animal behavior
  - Animal ability to detect the device
  - Animal behavior in response to the device

- **Outcomes**: Probabilities of encounter/collision
  Did the animal survive after collision? If not, what is the effect on the population?

Types of Models

To estimate interactions between animals and devices:

- **Encounter Rate Model**: estimates the likelihood of being in the nearfield of the turbine
- **Collision Risk Model**: estimates the probability of contact between an animal and the turbine

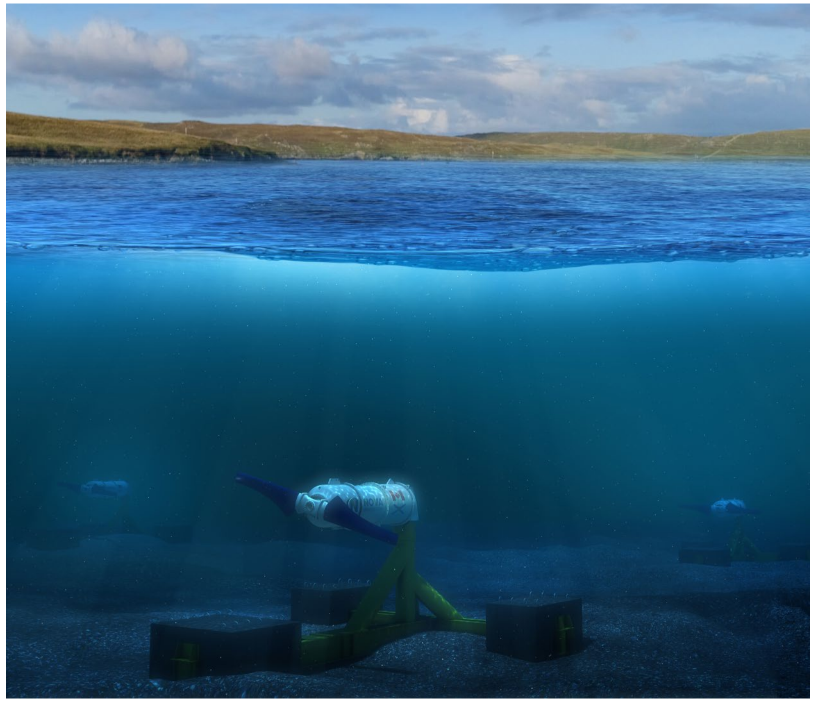
To estimate the potential effect of a collision to the population:

- **Exposure Time Population Model**: associates collision risk to population effects by estimating the rates of fatal collision that leads to a specified detrimental effect on the population

Encounter Rate Model

Wilson et al. 2007

- Predator-prey model integrating:
  - Volume of water swept by a predator (i.e., the blade of a turbine)
  - Size of the prey
  - Prey density
  - Relative swimming speeds of predator and prey (i.e., blade and animal)



Nova Innovation

- A turbine blade, viewed from the side, sweeps a certain volume of water in a unit of time that an animal has some probability of occupying.

→ Estimate the likelihood of encounter between prey and predator
Best suited for horizontal axis turbine

Collision Risk – Numerical Model

- Based on Band (2012): birds and offshore wind farm

- Model integrating:
  - Area covered by the rotor
  - Size of the animal
  - Animal's transit time across the plane of the rotor
  - Animal's behavior and density

➡ Estimate the probability of collision between an animal and a turbine
Sensitive to assumptions about avoidance rate
Best suited for horizontal axis turbine

Few models included avoidance/evasion behavior

- Based on behavioral observations of fish
(Hammar et al. 2015)
- Injury risk based on the part of the animal's body that contacts the rotor
(Copping and Grear 2018)

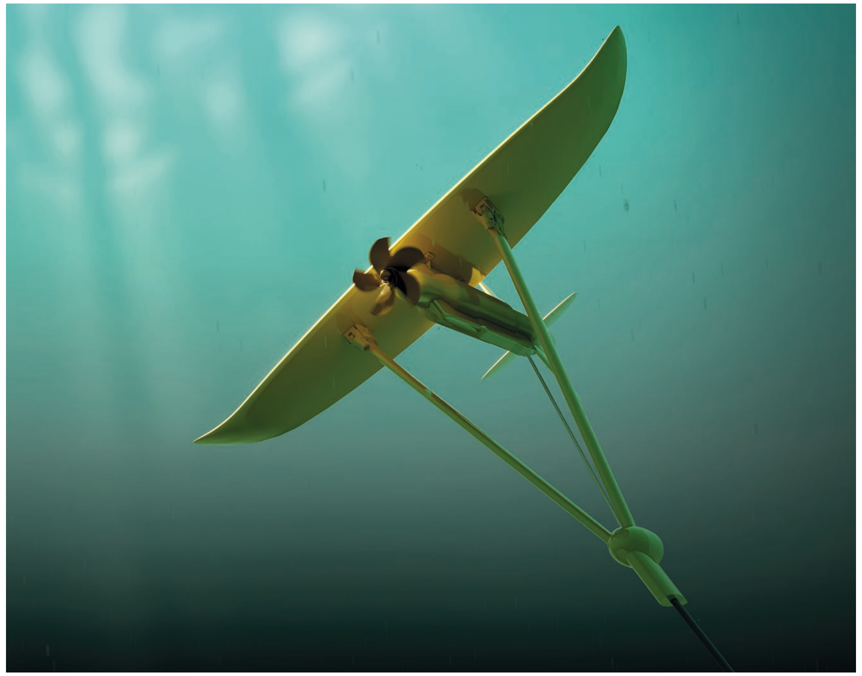
Collision Risk – Spatial Simulation

- 3D representation of an animal and a device over time

- Model integrating:
  - Shape and movement of a device
  - Animal's behavior
  - Animal's size

→ Estimate the probability of collision between an animal and a device
Variation in input parameters influences collision probabilities (e.g., vertical migration)

- Integration of the relative complexity of a tidal kite (Horne et al. 2021)
- Interactions with flow (Rossington and Benson 2020)



Minesto

Exposure Time Population Model

- Developed for diving birds (Grant et al. 2014)

- Approaches collision risk from the perspective of populations

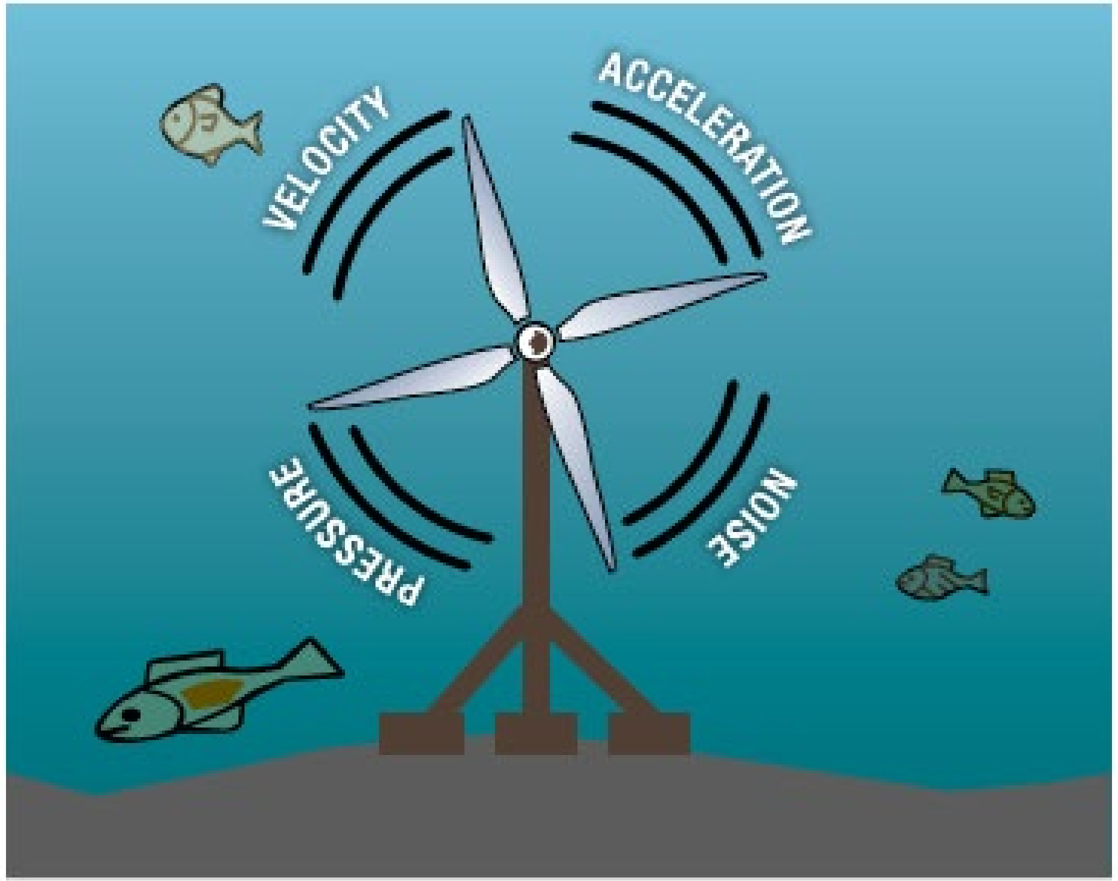
- Model integrating:
  - **Population model**: to estimate the amount of additional mortality caused by collisions that would not decrease the population growth rate
  - **Exposure time model**: to estimate collision probability from the amount of time animals spend at the depth of the device and the proportion of that depth occupied by the device

→ Estimate of collision risk per unit of time based on the population size and individual exposure time
Provides the threshold mortality rate

- Assumes that every collision is fatal
- Does not include avoidance/evasion behavior

Inputs Required - Fish

- Population density
- Swimming speed
- Body size (length/width)
- Behavior (vertical migration)
- Reproduction and survival of the population (for ETPM only)



by Robyn Ricks

Conclusions on Collision Risk Models

- Probabilities of encounter/collision
  Mortality threshold that would affect a population

- Behavior can have large effects on model outcomes
  - Create uncertainties when using behavior with limited information

- Injury outcomes, death, and population effects usually not considered in models

- Model outputs mainly predicted for one single turbine, what about arrays?
  - Fish strike probabilities (Bevelhimer et al 2016)

➡ Empirical parameterization of behavior/density in models is rare
No existing validation of predicted collision probabilities

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Thank you

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Helping develop collision risk models for fishes

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ACEP Alaska Center for Energy and Power

PMEC Pacific Marine Energy Center

Collision risk for fishes: what is known, what is not known, and how do we collect it?

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ACEP Alaska Center for Energy and Power

PMEC Pacific Marine Energy Center

What is known

- Research is in its infancy
  - Not much known, compared to more mature fields
  - Largely non-transferable results:
    - Different approaches
    - Different fishes
    - Different environmental characteristics

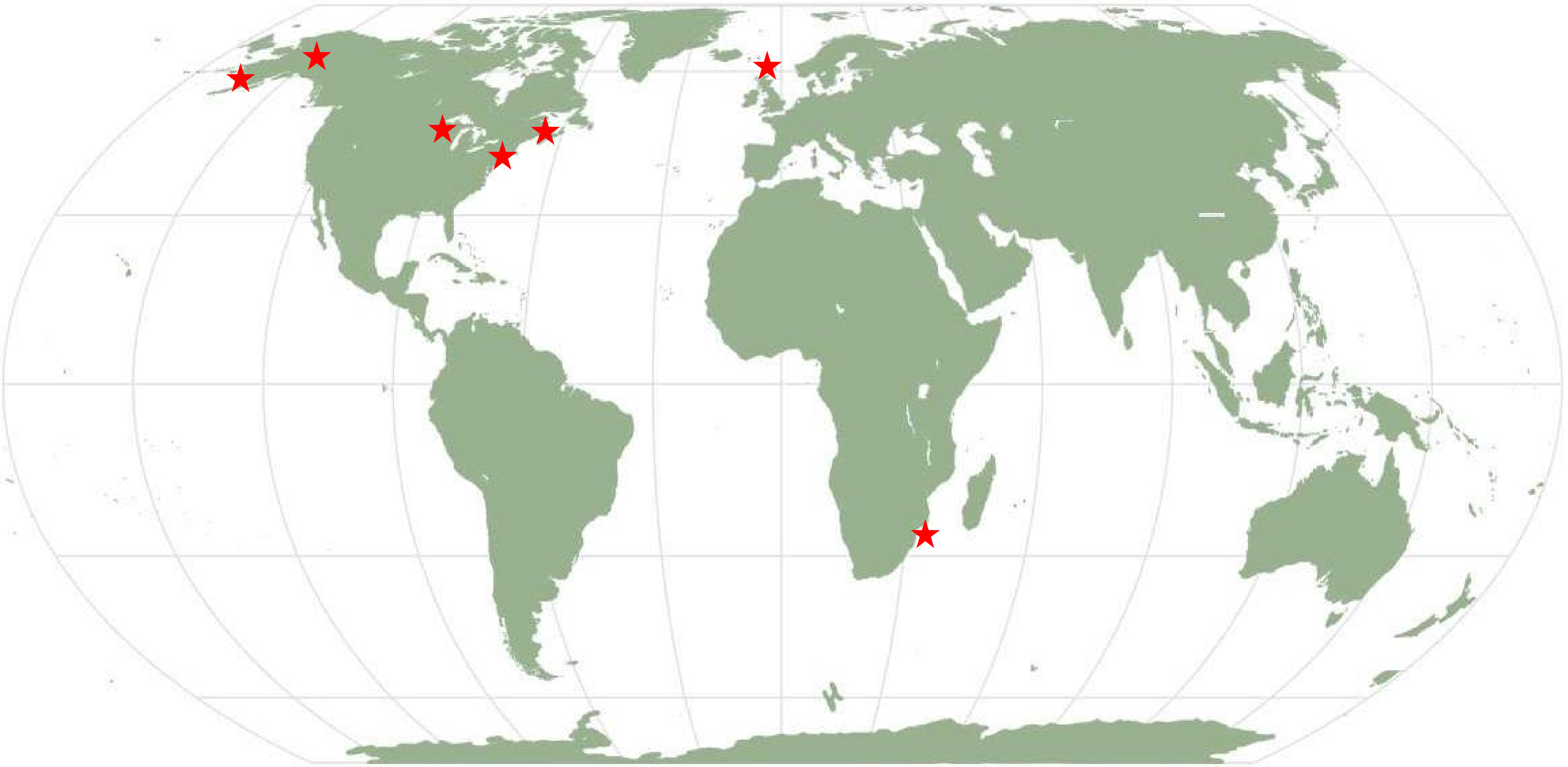
Nemeth et al. 2014

What is known

- Search of TETHYS

- Personal experience

What is known: study locations



What is known: study species

- In situ studies:
  - In many cases, unknown
  - Atlantic herring (*Clupea harengus*)
  - Atlantic mackerel (*Scomber scombrus*)
  - alewife (*Alosa pseudoharengus*)
  - threespine stickleback (*Gasterosteus aculeatus*)
  - pollack (*Pollachius pollachius*)
  - saithe (*Pollachius virens*)
  - sprat (*Sprattus sprattus*)
  - sandeels (*Ammodytes spp.*)
  - Pacific salmon (*Oncorhynchus* spp.*)*

- Flume studies
  - rainbow trout (*Oncorhynchus mykiss*)
  - striped bass (*Morone saxatalis*)
  - hybrid striped bass (*Morone saxatalis x chrysops*)
  - white sturgeon (*Acipenser transmontanus*)
  - Japanese rice fish (*Oryzias latipes*)
  - walleye/sauger (*Stizostedion* spp.)
  - crappie hybrid (*Pomoxis* spp.)
  - fathead minnows (*Pimephales promelas*)
  - yellow perch (*Perca flavescens*)
  - channel catfish (*Ictalurus punctatus*)
  - bluegill sunfish (*Lepomis macrochirus*)
  - Buffalo (*Ictiobus* spp.)

What is known: study species

- In situ studies:

Table 2. Detailed results showing effects on gap passages for fish genera contributing to most of the dissimilarity between control and impact treatment.

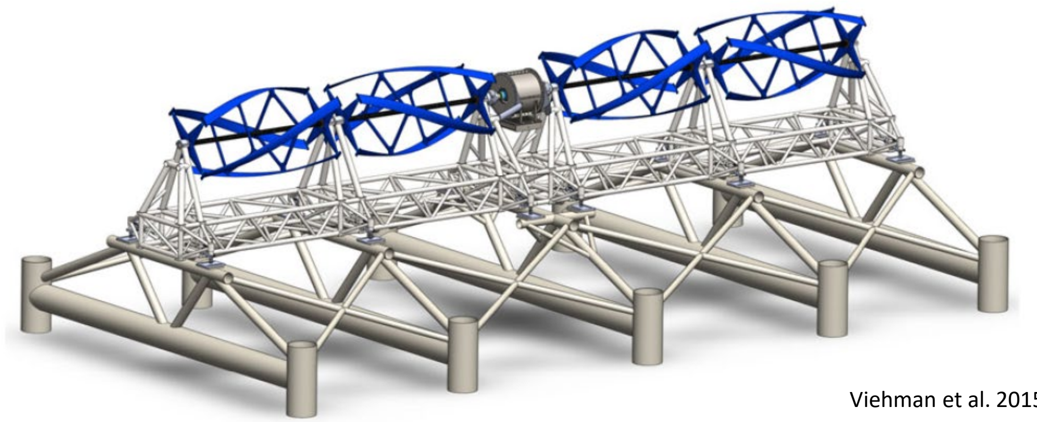
Genus	Feeding guild	Body shape	Swimming style	*D* (%)	∑ control (A)	∑ impact (A)	P (A)	∑ control (B)	∑ impact (B)	P (B)
Acanthurus	Browsers	Compressiform	Carangiform	14	190	68	**0.000**	91	5	**0.000**
Chaetodon	Browsers	Compressiform	Carangiform	12	142	50	**0.005**	79	12	**0.011**
Rhabdosargus	Inv. feeders	Fusiform	Carangiform	10	125	71	0.989	101	57	0.912
Ctenochaetus	Browsers	Compressiform	Carangiform	9	131	43	**0.006**	70	18	0.052
Siganus	Browsers	Compressiform	Carangiform	8	95	6	**0.000**	57	0	**0.000**
Thalassoma	Inv. feeders	Fusiform	Labriform	8	113	78	0.478	85	31	**0.019**
Scarus	Browsers	Fusiform	Subcarangiform	7	93	17	**0.000**	53	6	**0.015**
Sufflamen	Inv. feeders	Compressiform	Balistiform	3	17	25	0.191	14	11	0.853
Centropyge	Browsers	Compressiform	Carangiform	3	32	3	0.277	1	0	0.739
Kyphosus	Browsers	Fusiform	Subcarangiform	3	31	1	0.265	0	0	-
Plectorhinchus	Inv./fish feeders	Fusiform	Subcarangiform	3	25	11	0.341	18	7	0.353
Lethrinus	Inv./fish feeders	Fusiform	Carangiform	2	24	19	0.620	11	10	0.739
Pomacanthus	Browsers	Compressiform	Carangiform	2	18	7	0.192	4	0	0.739
Lutjanus	Inv./fish feeders	Fusiform	Carangiform	2	16	1	0.174	8	1	0.247
Parupeneus	Inv. feeders	Fusiform	Subcarangiform	2	13	3	0.072	7	0	**0.007**
Bodianus	Inv. feeders	Fusiform	Labriform	1	14	8	0.512	11	6	0.529
Scolopsis	Inv. feeders	Fusiform	Carangiform	1	6	11	0.738	2	1	0.739

The first columns indicate the taxonomic identity and categories of fish. The genera-specific contribution to the assemblage dissimilarity between fish passing through the gap during control (no rotor) and impact (rotor) is indicated by *D*. Total numbers of gap passages and significance values (*P*) for effects of the rotor (Mann–Whitney *U* tests, using 2×1-sided exact *P*) are presented separately for (A) all samples (n=20) and for (B) samples in current speeds above 0.6 ms^{-1} (n=10). Significant effects are indicated in bold. All non-significant results were associated with low power (<0.8). Only fish genera cumulatively contributing to 90% of the assemblage difference are shown in the table.

doi: 10.1371/journal.pone.0084141.t002

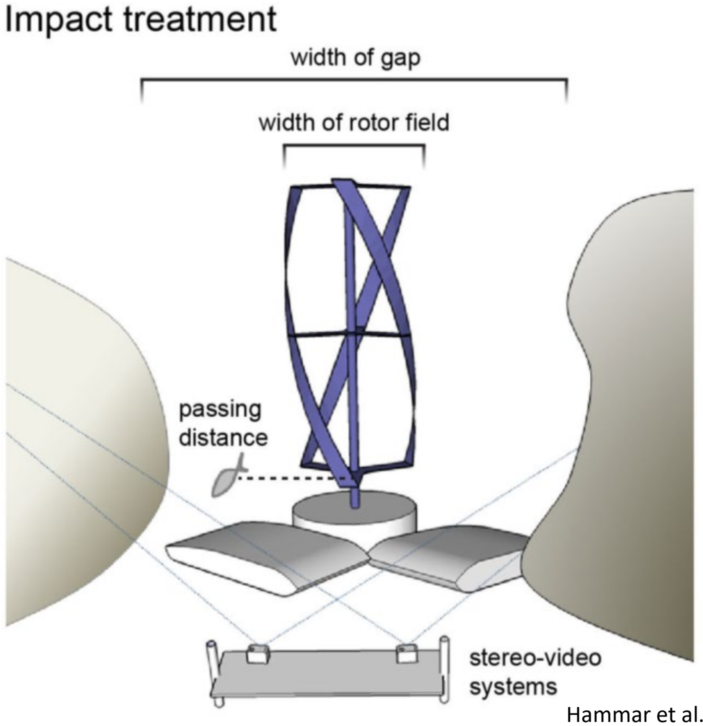
Hammar et al. 2013

What is known: turbines

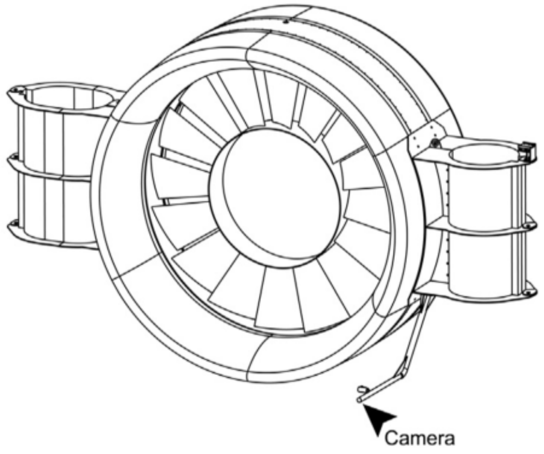


Viehman et al. 2015

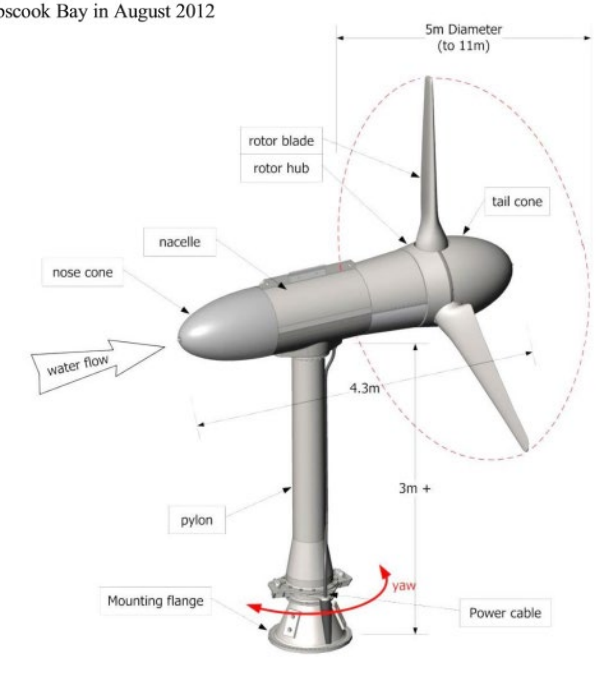
Fig. 1 Ocean Renewable Power Company's TidGen® device (drawing courtesy of ORPC), installed in outer Cobscook Bay in August 2012



Hammar et al. 2013



Broadhurst et al. 2014



Verdant Power Gen 5 KHPS Turbine

Dean Corren 2014

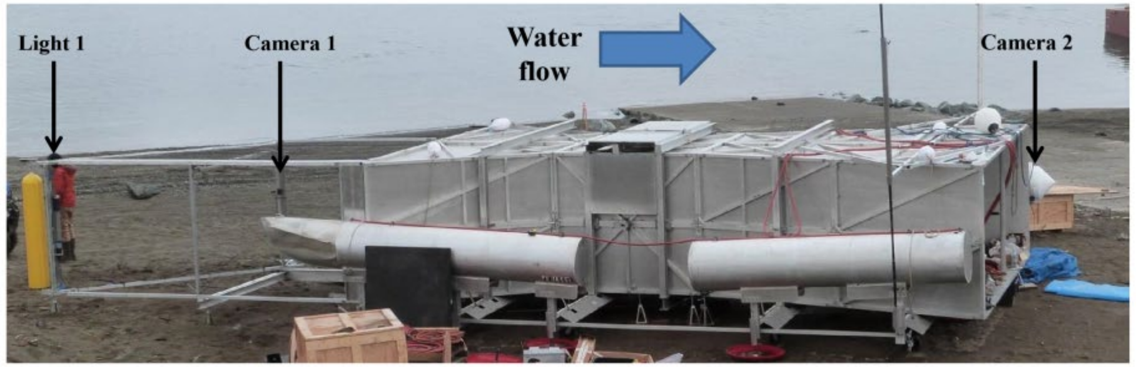


Photo 2. BRI device before deployment, showing mount locations of underwater cameras and light used during deployment in 2014. Water would flow from left to right.

Nemeth et al. 2014

What is known: monitoring approaches

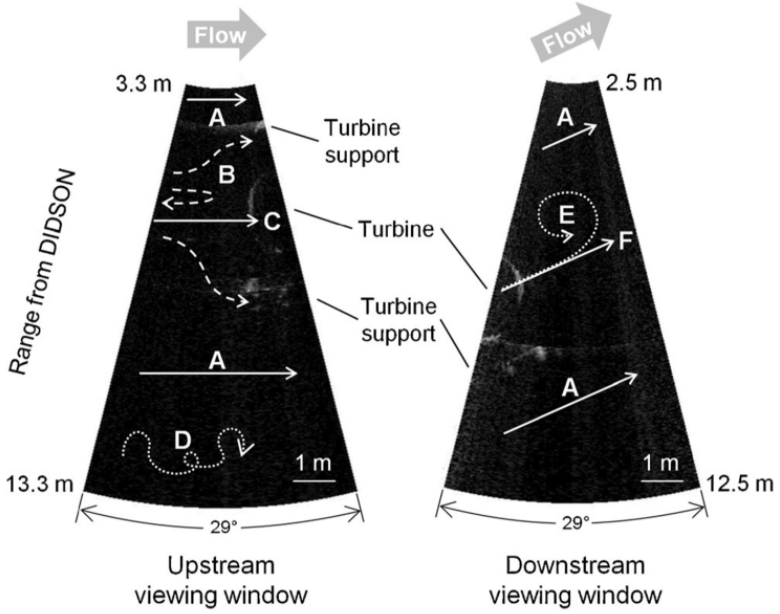


Fig. 3 Sample frames from upstream (*left*) and downstream (*right*) DIDSON units, showing cross-section of the test turbine and its support frame. Fish behaviors illustrated are **a** passing, **b** avoiding, **c** entering, **d** milling, **e** exiting and remaining in wake, and **f** exiting and moving through the wake. Water flow in the downstream view is angled upward due to the angle of the DIDSON   Viehman, H.A., and Zydlewski, G.B. 2015

Figure 4. Example of *Rhabdosargus sarba* (F.) evasion manoeuvre. Goldline stumpnose *R. sarba* carrying out a typical evasion manoeuvre as the specimen passes through the gap against a 0.7 ms^{-1} current speed. The fish changed its trajectory 45° with a quick burst as it was startled by the approaching rotor blade at 22 cm distance. The image was extracted from the analysed video material (right camera).

doi: 10.1371/journal.pone.0084141.g004   Hammar et al. 2013

H. Shen et al. / Renewable Energy 97 (2016) 746–756   749

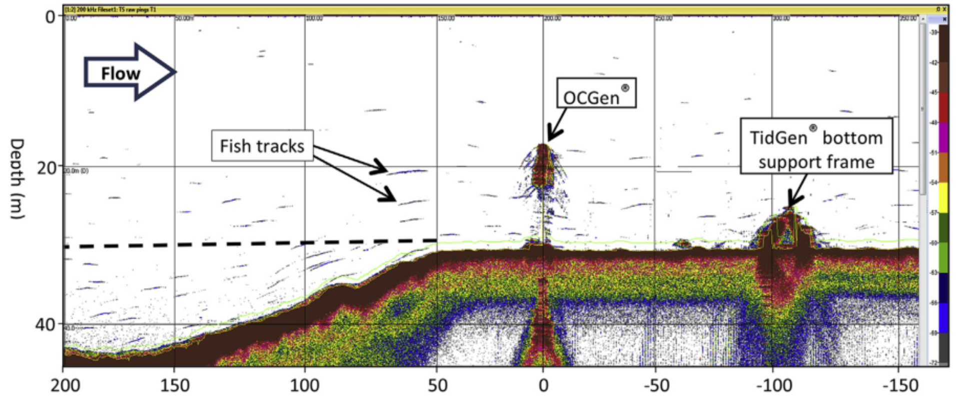


Fig. 3. One mobile transect over the OCGen® and the TidGen® bottom support frame during a flood tide. Fish tracks below the dashed line were excluded from analysis to ensure equal amounts of water sampled during the length of one transect.

What is known

- Distribution
  - Fish shoal around turbines
  - Attraction effect, may use for protection and feeding
  - Attraction/abundance inversely related to tidal velocity

SABELLA / Y.GLADU

What is known

- Behavior
  - Fish can avoid turbines
  - Fewer interactions when turbine spinning
  - Schools react farther away than individuals
  - No evidence of passage delay for migrators
  - Turbine entry higher during night

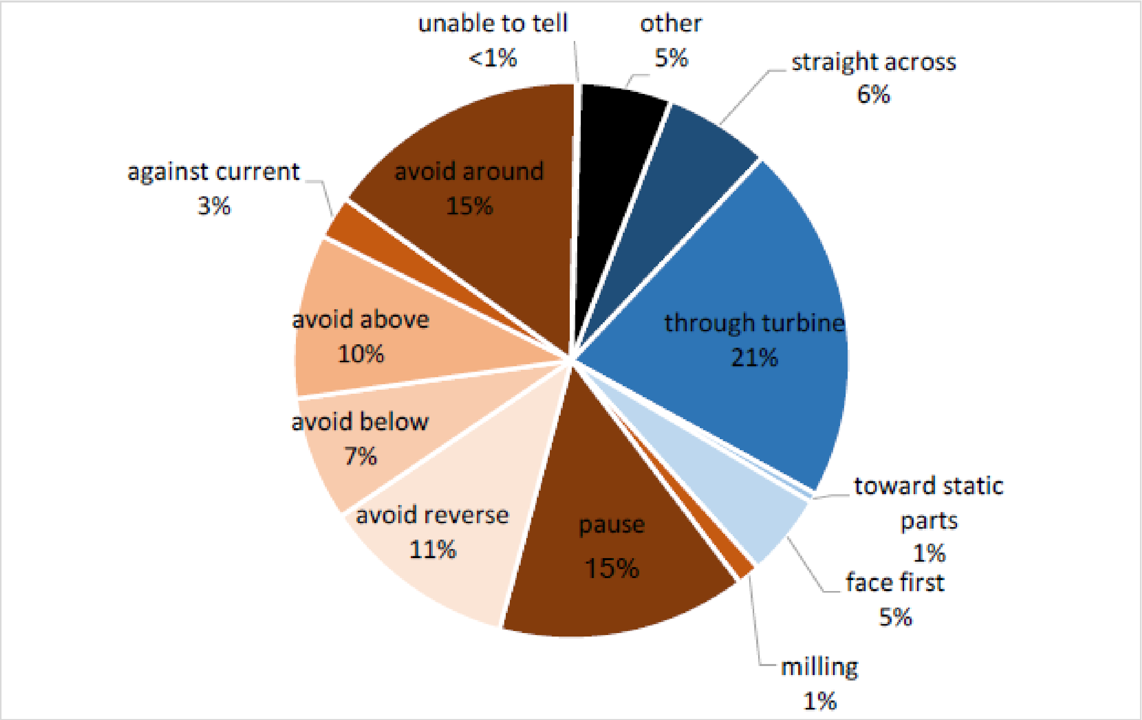


Figure 3.5. Behavior types recorded by reviewers for Fish Events in Nighttime Data for all sizes (n = 618).
Maybe and Combination events were removed. The blue sections of the graph designate the Passive group of behaviors and the brown sections represent the Avoidance group of behaviors.

Matzner et al. 2017

What is known

- Passing through turbines
  - No obvious injuries for fish passing through turbines
  - Harm and mortality depends on::
    - Species
    - Age
    - Entry angle
    - Turbine characteristics

Figure 2. Investigator measuring flow velocities near location of larval fish insertion point.

Schweizer et al. 2012

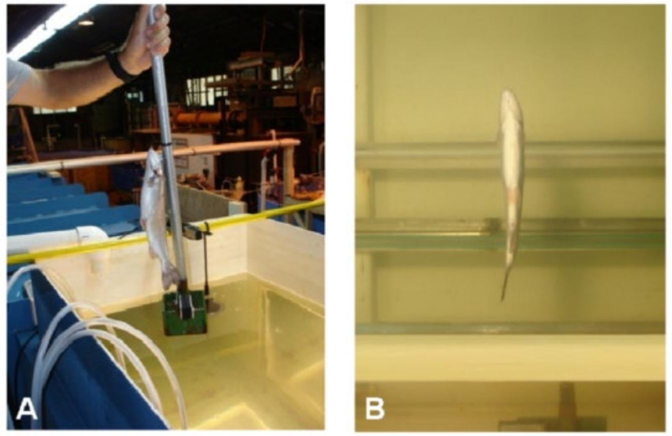


Figure 2-4
Rainbow Trout Being Placed in Test Tank (A) and Positioned Prior to Strike By Blade Moving from Right To Left in (B)

EPRI 2011

What needs to be known

- Broader research
  - Near field events (<10 m)
  - Identifying collision vs. near-miss
  - Night time events and lights
  - Monitoring approaches/systems
  - Automated analyses

- Project/location/species specific
  - Effects on mass migration
  - Direct blade strike effects
  - Condition of fish passing through turbine
  - Multiple deployments
  - Cumulative impacts
  - Relationships between turbine characteristics and fish behavior

How do we collect information?

- Develop more standardized approaches or best practices
- Apply these to field studies:
  - Baseline: fish presence/absence
  - Interactions: behavior in relation to environmental fields
  - Outcomes
- **Modeling will be dependent on root understanding of species-specific behavior**

Questions?

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working to accelerate offshore consenting

Collision risk modelling in practise - Fish

OES Environmental & ORJIP OE Workshop, 16/03/2021

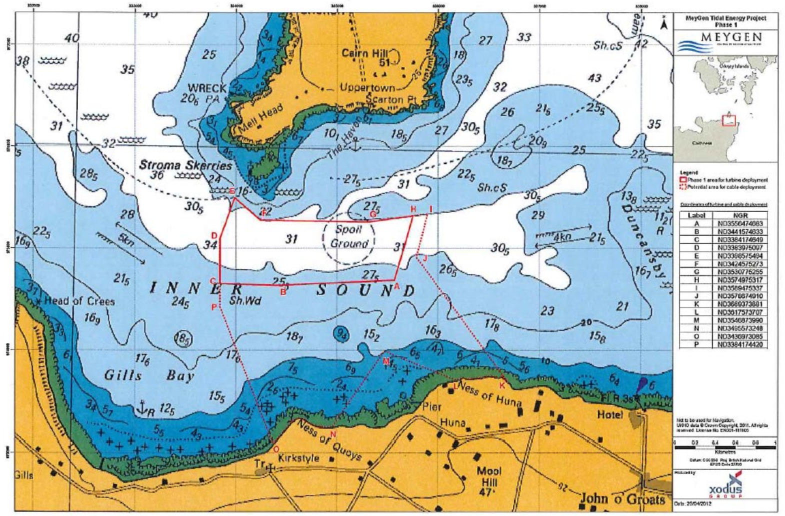
Raeanne Miller, Senior Consultant, Aquatera

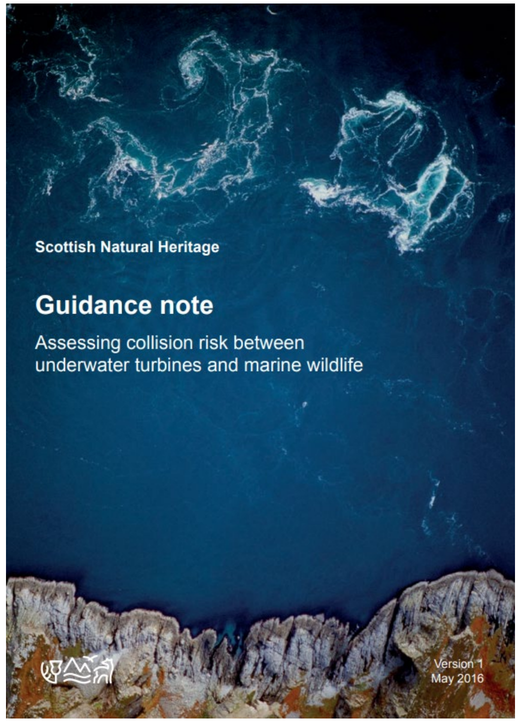
MeyGen

- 2014- EIA completed and Marine License granted
- 2015- Onshore construction commenced
- 2018- MeyGen Phase 1A officially enters into operation
- Consent was sought in phases
  - Phase 1 consent for 86 MW Phase 2 consent will be sought separately (312 MW)
- Turbines 1 MW capacity each, with an export cable to shore each

Source: Gillespie, 2020 Presentation. OES Environmental International Monitoring Forum

- **MeyGen Environmental Statement (2012)**
  - Encounter rate modelling for Atlantic salmon (*Salmo salar*); 20 and 86 turbines evaluated
- **MSS / SNH Review of MeyGen Atlantic salmon Modelling (2013)**
  - Reviewed and repeated modelling with additional data
- **Scottish Natural Heritage (NatureScot) 2016 guidance**
  - Worked Example: Encounter rate modelling for Atlantic salmon, 86 turbines
  - New depth distribution data (Godfrey *et al.* 2015)





Atlantic salmon in the Pentland Firth

13 Fish Ecology

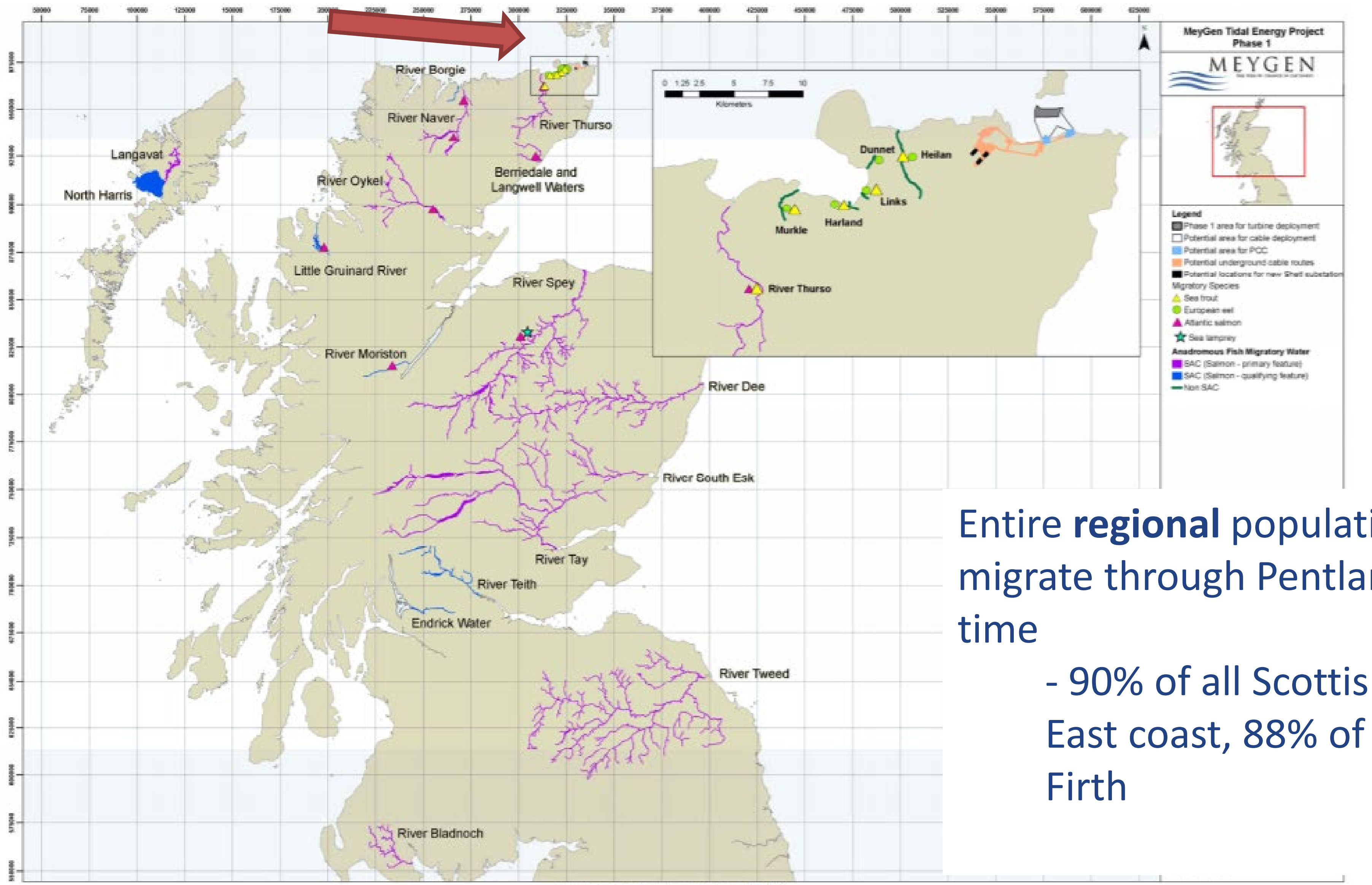


Figure 13.1: Diadromous fish rivers and SACs

Entire **regional** population of Atlantic salmon migrate through Pentland Firth at the same time

- 90% of all Scottish salmon return to the East coast, 88% of those via the Pentland Firth

Encounter Rate Modelling

- Most comprehensive data for salmon, vs other species of fish (e.g. sandeel)
- Estimate probability of a smolt, a grilse (1st year salmon), and multi-sea-winter (MSW) adults encountering turbines
  - Frontal area of turbine/array
  - Depth distribution of fish (uniform/varied)
  - Proportion of population passing through ‘array space’
  - Proportion of fish surviving passing through turbine
- Various avoidance rates applied to encounter rates
- In MSS-SNH review risk to smolts deemed low – small size, no strong indication that Scottish smolts migrate through the Pentland Firth

Comparing approaches

MeyGen (2012)	MSS-SNH (2013)	SNH (2016)
90% E coast salmon go through PF	90% is a precautionary figure (in reality, 79% of adult salmon returning to Scottish waters)*	90% is a precautionary figure (in reality, 79% of adult salmon returning to Scottish waters)*
Adult salmon uniformly distributed across PF cross-sectional area (inc. with depth)	Adjust adult vertical distribution based on tagging data**	Updated vertical distributions (Godfrey *et al*. 2015)
57% adults at turbine depth	**16.6% adults at turbine depth**	**10.6% of salmon within risk depth**

*88% estimated to originate from E coast rivers, & 90% were thought to migrate through northerly channels (e.g. PF, 0.88*0.9 =0.792)

**note that tagging data did not include data from fast, reversing tidal streams

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Comparing approaches

MeyGen (2012)	MSS-SNH (2013)	SNH (2016)
Rotational plane of one turbine = 0.0945% PF cross-sectional area	Rotational plane of one turbine = 0.0945% PF cross-sectional area	
Effective rotational plane **1 row x 11 turbines= 1.04% PF, 2 rows x 11 turbines = 2.08% PF** (considered as cross-sectional area of 86 turbine array)	Effective rotational plane 20 & 86 turbines: **20*0.0945 = 1.89% PF and 86*0.0945 = 8.127% PF**	
72% turbine operation rate	**72% turbine operation rate**	**82.7% turbine operational time (17.3% non-operational)**

Comparing approaches

MeyGen (2012)	MSS-SNH (2013)	SNH (2016)
0.282 of grilse and 0.330 of adult salmon passing through the turbines would be expected to collide	No fish avoid turbines, but 0.3 of adult salmon collide, 0.7 of adult salmon passing through turbines are expected to survive	Collision probability for a single transit: 11.6% for smolt, 32.4% for grilse 37.2% for MSW salmon
Avoidance rates 50%-99.5%	Suggested inclusion of a 0% avoidance rate	Numerous avoidance rates used

The bottom line

- **MeyGen Environmental Statement**
  - 1,044 grilse and 911 adults are expected to encounter a turbine (0.38% and 0.45% of population)
  - Application of avoidance rates decrease population level effects (0.2% adults, at 50% avoidance)
- **MSS-SNH review:**
  - 6 turbines: 171 adult salmon are predicted to collide out of an adult population of 540,000
    - no active avoidance assumed, turbine pass survival rate 0.7
    - Or, 13 salmon lost from an annual harvest of 40,000, assuming linear scaling

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The bottom line

- **SNH Guidance note 2016 (Band 2016), vs. MeyGen ES**

- Potential collisions per year, with no avoidance assumed, are:

	MeyGen (2012)	SNH/Band (2016)
Smolts	13,614	13,054
Grilse	1,044	1365
Adults (MSW)	911	1171

- Assuming 95% avoidance:

	MeyGen (2012)	SNH/Band (2016)
Smolts	681	653
Grilse	52	68
Adults (MSW)	46	59

Differences attributed to:

- **Full frontal area of all 86 turbines being taken into account,**
- **Updated depth distributions**
- **Blade twist also better reflected**

Mitigation measures

- No significant impact has been identified, but:
  - Undertake post-installation monitoring, agreed with Marine Scotland
  - No specific mitigation identified, but continue to work with Marine Scotland and advisors on ongoing research, monitoring, and mitigation strategies

Hans-Petter Fjeld, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=43160800

References

- **MeyGen Environmental Statement: Fish Chapter**
  - https://www.waveandtidalknowledgenetwork.com/wp-content/uploads/legacy-files/MeyGen_Phase1_ES_Section_13_Fish_Ecology.pdf
- **MSS-SNH Review of MeyGen modelling for Atlantic salmon**
  - http://marine.gov.scot/datafiles/lot/Meygen/June_2013_MSS_SNH_report-Consideration_of_Atlantic_Salmon_Collision_Modelling/20130607_Meygen_Salmon_review-Final_PDF_Version_A951792.pdf
- **Scottish Natural Heritage (now NatureScot) Guidance note Assessing collision risk between underwater turbines and marine wildlife**
  - https://www.nature.scot/sites/default/files/2017-09/Guidance%20Note%20-%20Assessing%20collision%20risk%20between%20underwater%20turbines%20and%20marine%20wildlife.pdf
- **Godfrey, J.D., Stewart, D.C., Middlemas, S.J. & Armstrong, J.D. 2015. Depth use and migratory behaviour of homing Atlantic salmon (Salmo salar) in Scottish coastal waters.** ICES Journal of Marine Science, Early View July 2014. doi.10.1093/icesjms/fsu118

Thank You!

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Ocean Energy orjip working to accelerate offshore consenting

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