Understanding vessel size and speed as factors in preventing ship strikes of marine mammals*

Sean Brillant
Canadian Wildlife Federation
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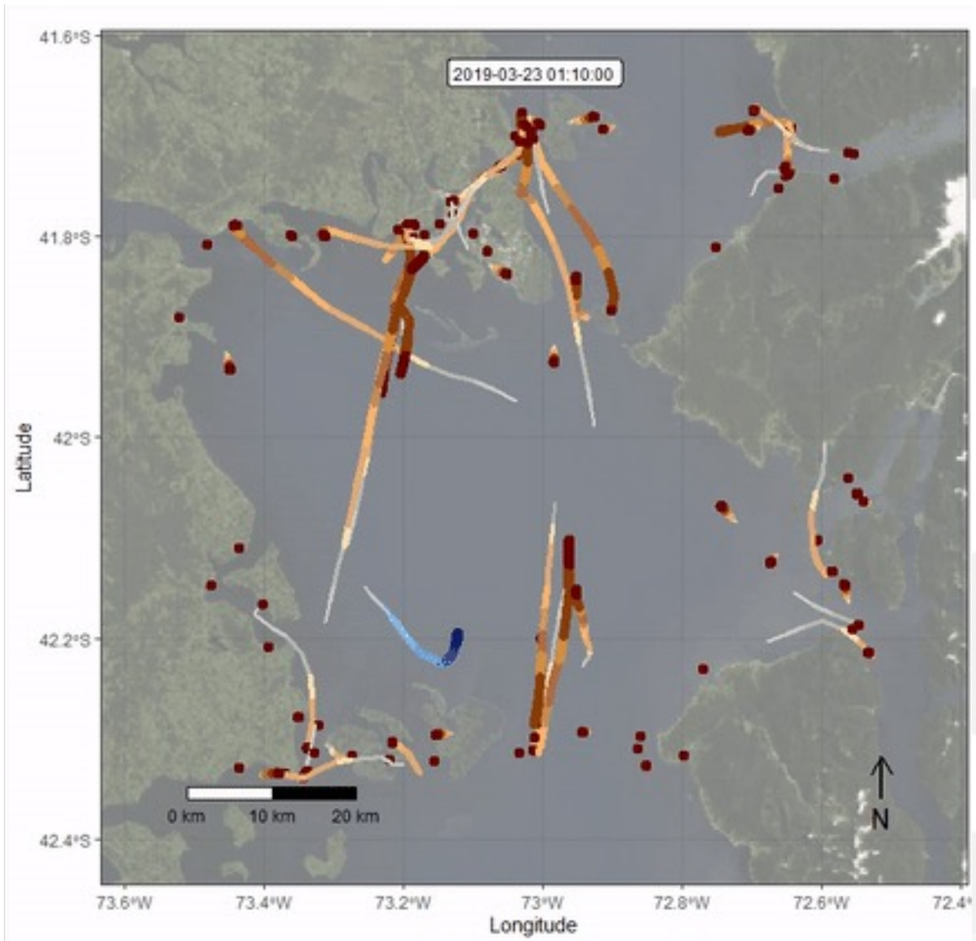

Tagged blue whale amid aquaculture traffic in Chile

Bedriñana-Romano et al. 2021. *Sci Rep* 11, 2709.

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Ship strikes are a global issue
75 species known to be affected
10s of ,000s individuals annually
NOAA- NEFSC

North Atlantic right whales

Vessel strikes*
13% of injuries
51% of mortalities

*only 36% of killed NARW are ever detected

Pace et al. (2020) Cryptic mortality of North Atlantic right whales. Cons Sci Prac

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Options for reducing ship strikes lethality:

- Separation from whales
- Speed restrictions
- Early detection and avoidance

Non-option: Deterrents (e.g. acoustic)

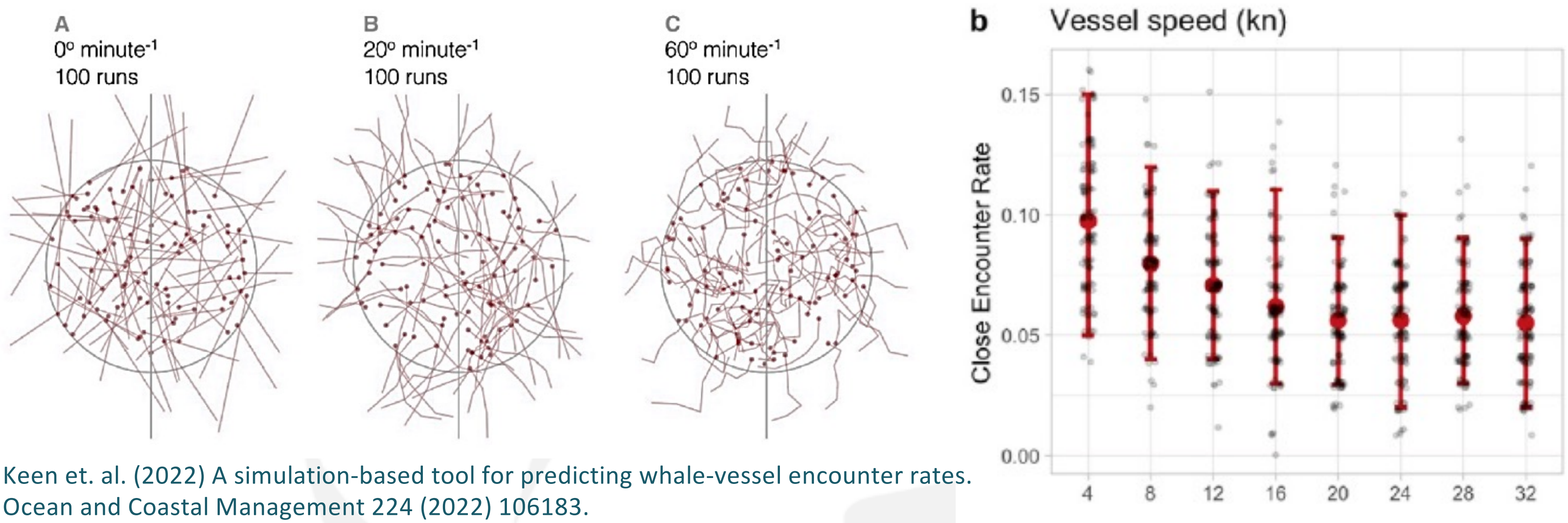
Uninvestigated: Redesigning ships

ANUCHA SIRIVISANSUWAN/GETTY IMAGES

Understanding vessel size and speed as factors in preventing ship strikes of marine mammals*

"Preventing vessel strikes" → eliminating encounters

Vessel size and speed has <u>negligible effect</u> on **encounter rate**



Keen et. al. (2022) A simulation-based tool for predicting whale-vessel encounter rates. Ocean and Coastal Management 224 (2022) 106183.

Vessel size and speed have <u>large effects</u> on **lethality**!

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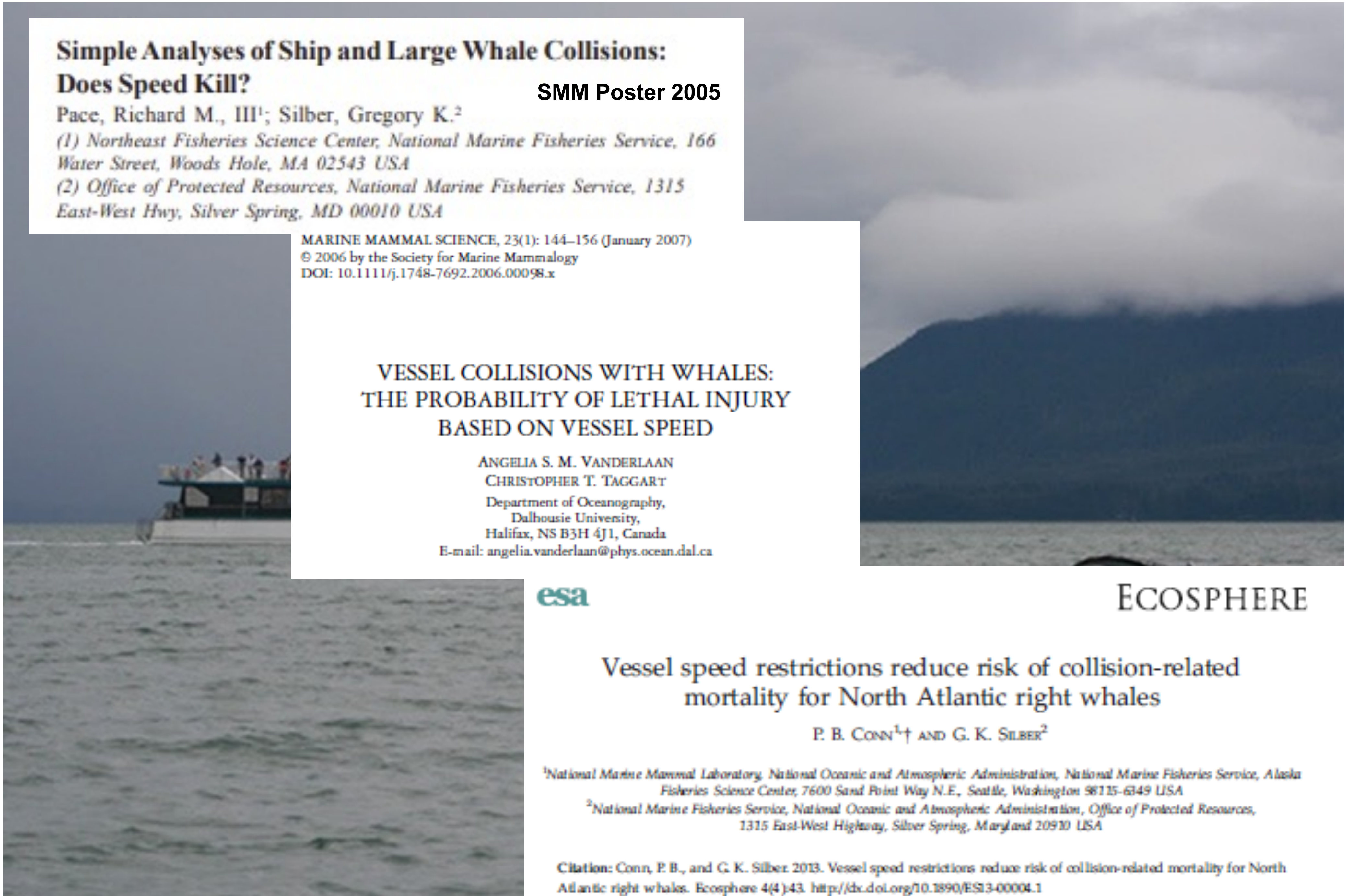

Simple Analyses of Ship and Large Whale Collisions: Does Speed Kill?

SMM Poster 2005

Pace, Richard M., III[1]; Silber, Gregory K.[2]
(1) Northeast Fisheries Science Center, National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543 USA
(2) Office of Protected Resources, National Marine Fisheries Service, 1315 East-West Hwy, Silver Spring, MD 00010 USA

MARINE MAMMAL SCIENCE, 23(1): 144–156 (January 2007)

DOI: 10.1111/j.1748-7692.2006.00098.x

VESSEL COLLISIONS WITH WHALES: THE PROBABILITY OF LETHAL INJURY BASED ON VESSEL SPEED

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esa ECOSPHERE

Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales

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[2]National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Office of Protected Resources, 1315 East-West Highway, Silver Spring, Maryland 20910 USA

Citation: Conn, P. B., and G. K. Silber. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. Ecosphere 4(4):43. http://dx.doi.org/10.1890/ES13-00004.1

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Sharp et al. 2019; IFAW

- 20-30% of whales killed by blunt-force have no broken bones
  (Jensen and Silber 2004, Campbell-Malone et al 2008, Sharp et al 2019)

- 3/4 whales necropsied and killed by blunt trauma in GoSL no broken bones
  (Daoust et al 2018)

- Massive hemorrhages

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1) What are the reactive forces involved in vessel-strikes?

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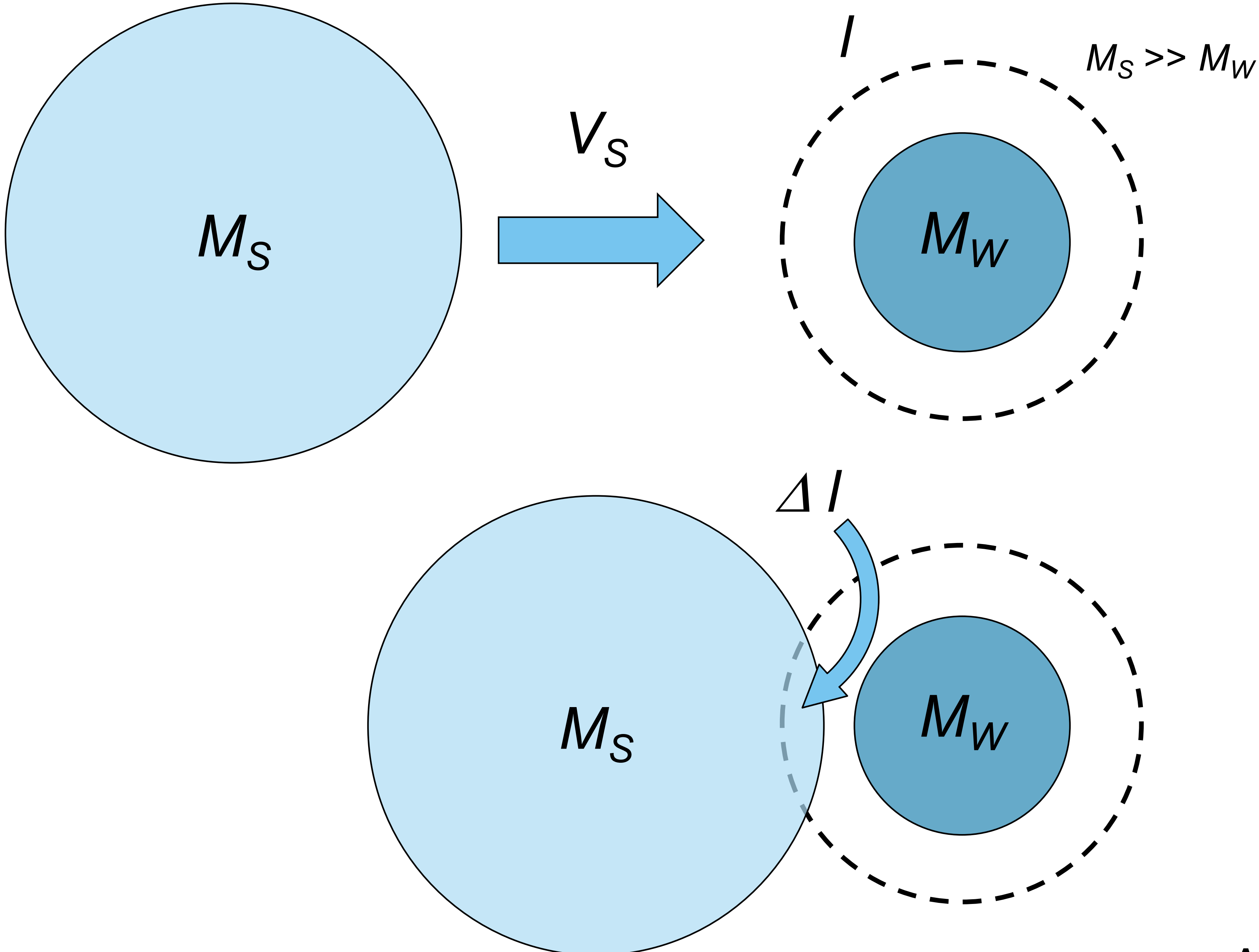
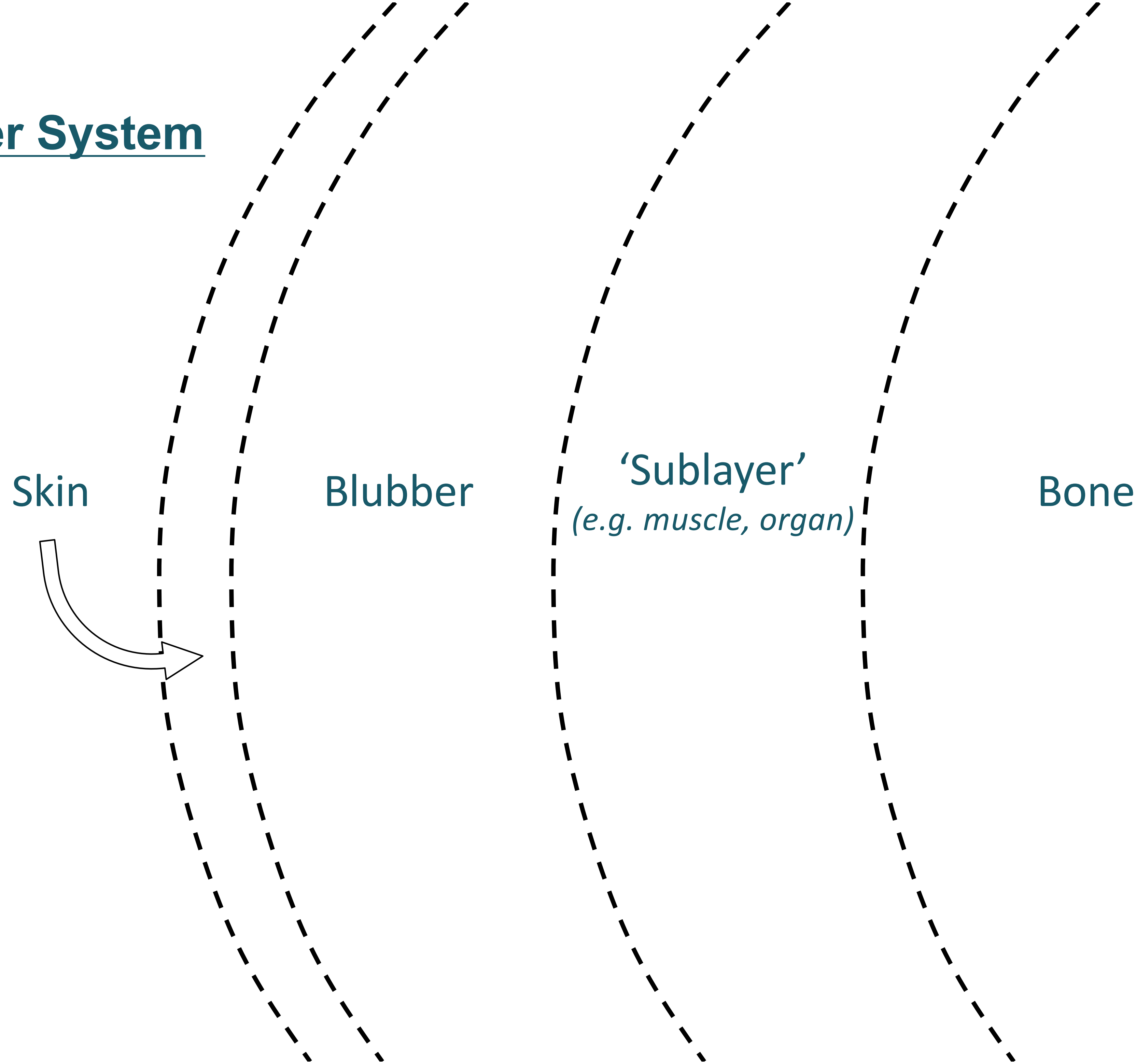
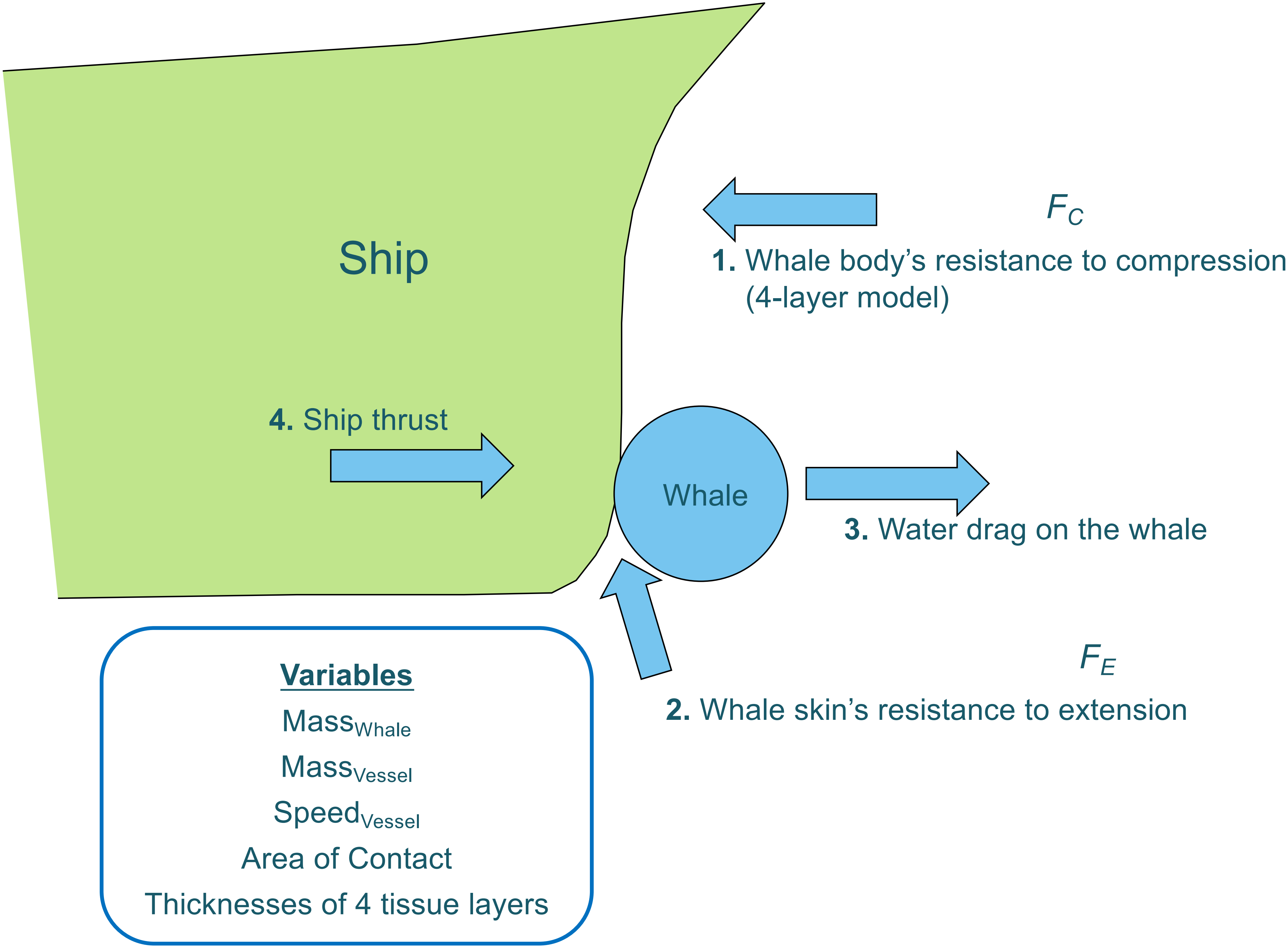


$$\boldsymbol{F} = Mass\ x\ Acceleration \qquad \boldsymbol{F} = \ Area \times E \times \frac{\Delta l}{l}$$

4-Layer System




Ship
1. Whale body's resistance to compression (4-layer model)
F_C
4. Ship thrust
Whale
3. Water drag on the whale
F_E
2. Whale skin's resistance to extension
Variables
$Mass_{Whale}$
$Mass_{Vessel}$
$Speed_{Vessel}$
Area of Contact
Thicknesses of 4 tissue layers

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FOR SALE

45 tonnes
@10 knots

= 0.45 MPa

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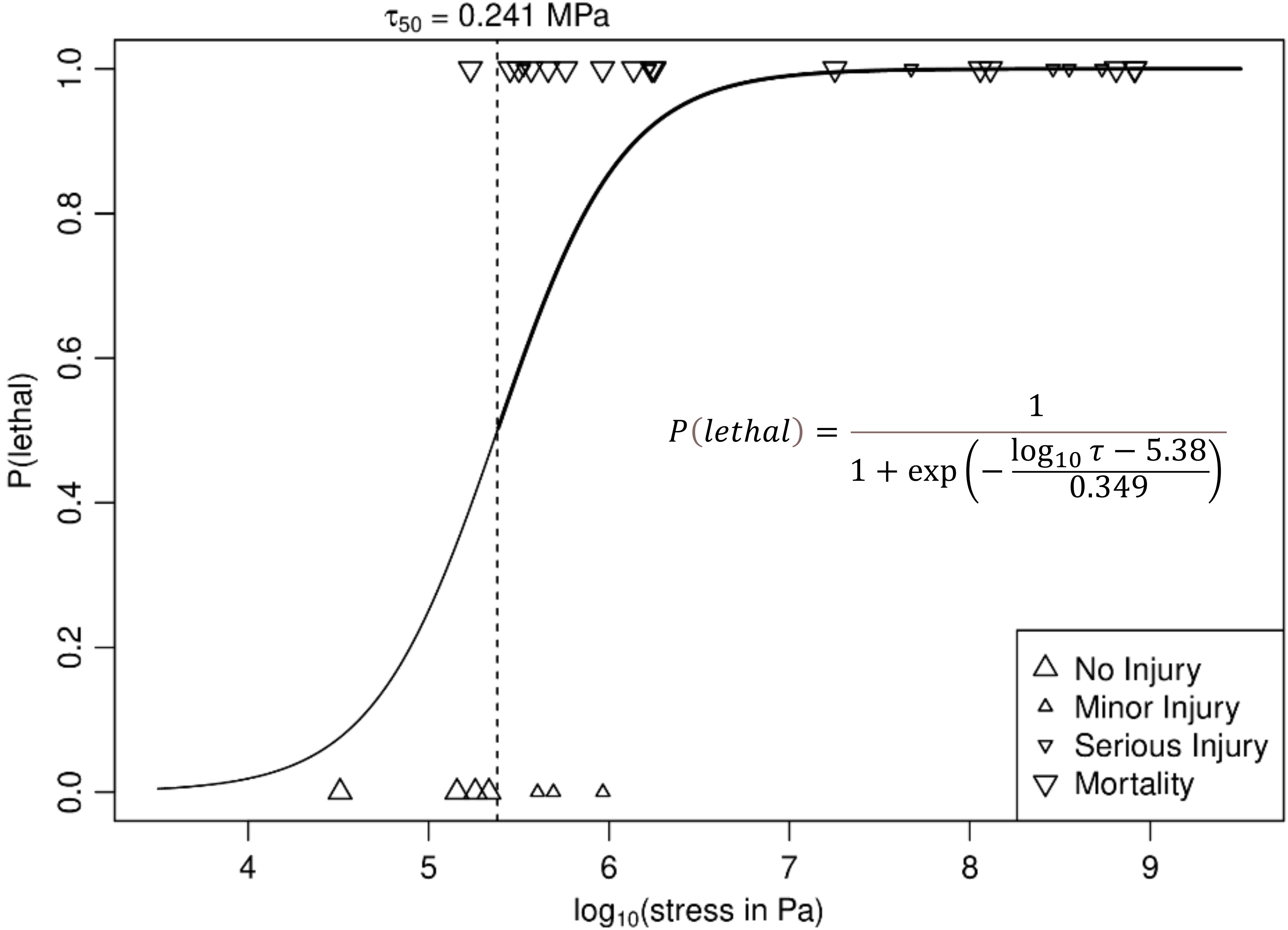
30,000 tonnes
@10 knots

= 0.95 MPa

2) Can we attribute consequences to these reactive forces from observed events?

TABLE 1 Reported ship strikes used to produce the lethality curve, where L (m) is length in meters, and Wt (t) is mass in tonnes. Fate is a description of the reported state of the whale after the ship strike; Uninjured and Killed are self-explanatory, and Minor and Serious each refer to the reported severity of the injury to the whale. Type is the reported description of the vessel where "HS Ferry" is a high-speed ferry, "USCG" is a US Coast Guard vessel, and "WW" is a whale watching vessel. Sp (kn) is the reported speed in knots of the vessel when the strike occurred. Max. stress is the maximum value of stress in megapascals computed during a numerical simulation with the four-layer model, based on the other properties listed in this table.

		Whale				Vessel					
Case	Date	Species	L (m)	Wt (t)[a]	Fate	Type	L (m)	Wt (t)[b]	Sp (kn)	Max. stress (MPa)	Reference
1	1885-01-01	Large whale	–	40	Minor	Pilot	–	60	13	0.92	Laist et al. 2001
2	1935-01-01	Large whale	–	40	Killed	Steamship	131	30,000	15	114.24	Laist et al. 2001
3	1953-11-01	Large whale	–	40	Killed	Navy	169	11,100	20	819.23	Laist et al. 2001
4	1955-03-22	Sperm whale	14	29	Killed	Steamship	144	30,000	17	1.78	Laist et al. 2001
5	1961-09-01	Large whale	–	40	Serious	Cargo	–	8,000	14	1.67	Laist et al. 2001
6	1972-12-01	Right whale	13	26	Killed	Container	207	24,182	22	647.77	Laist et al. 2001
7	1974-04-23	Large whale	–	40	Serious	Yacht	18	15	10.5	0.34	Laist et al. 2001
8	1974-12-01	Large whale	–	40	Serious	Ferry	–	4,000	17	540.24	Laist et al. 2001
9	1975-01-22	Gray whale	14	31	Killed	Navy	–	72	51	822.51	Laist et al. 2001
10	1980-07-05	Blue whale	30	183	Killed	Tanker	203	80,000	21	824.46	Laist et al. 2001
11	1984-08-01	Fin whale	24	80	Serious	WW	28	70	16	289.14	Laist et al. 2001
12	1988-09-07	Right whale	13	26	Killed	Ferry	171	8,000	12.5	0.92	Laist et al. 2001
13	1991-06-21	Humpback whale	15	49	Minor	WW	14	60	7.5	0.40	Laist et al. 2001
14	1991-07-06	Right whale	4.6	1	Killed	USCG	84	3,500	22	0.17	Laist et al. 2001
15	1992-02-01	Sperm whale	14	29	Killed	HS Ferry	20	5	45	17.88	Laist et al. 2001
16	1992-04-04	Large whale	–	40	Serious	Research	89	3,500	14	1.66	Laist et al. 2001
17	1992-05-15	Bryde's whale	12	12	Killed	Container	121	50,000	14	0.58	Laist et al. 2001
18	1993-09-09	Fin whale	24	80	Killed	Ferry	159	40,000	20	820.53	Laist et al. 2001
19	1995-06-01	Large whale	–	40	Minor	Fishing	27	60	9	0.49	Laist et al. 2001
20	1996-01-16	Humpback whale	15	49	Uninjured	WW	25	10	9	0.22	Jensen & Silber 2004
21	1996-05-16	Large whale	–	40	Serious	USCG	115	3,300	15	47.32	Laist et al. 2001
22	1997-01-01	Sperm whale	14	29	Killed	Ferry	100	11,000	25	819.40	Laist et al. 2001


τ_{50} = 0.241 MPa
P(lethal)
log10(stress in Pa)
$P(lethal) = \frac{1}{1 + \exp\left(-\frac{\log_{10}\tau - 5.38}{0.349}\right)}$
No Injury
Minor Injury
Serious Injury
Mortality
0.0
0.2
0.4
0.6
0.8
1.0
4
5
6
7
8
9

3) Putting it together.

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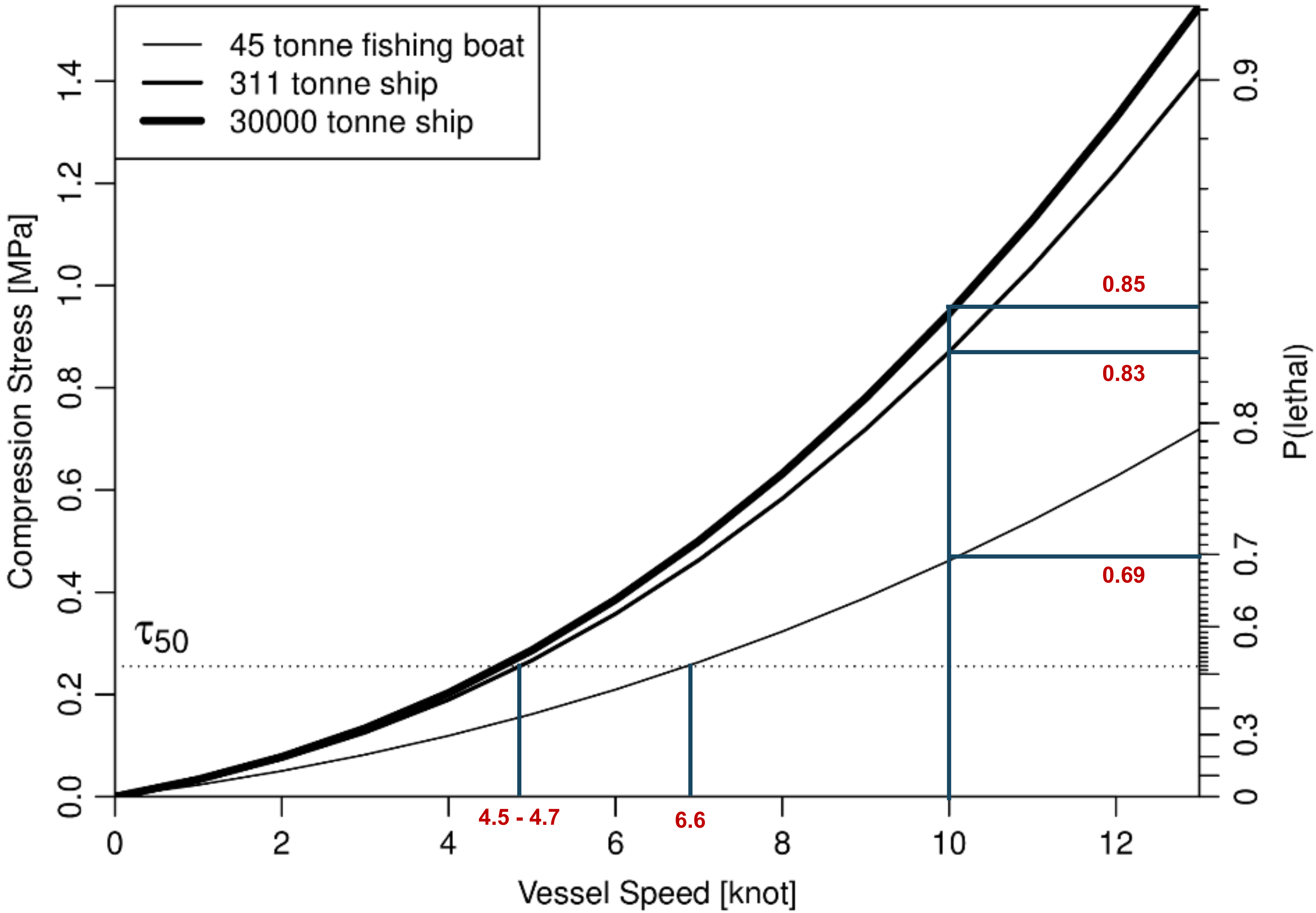
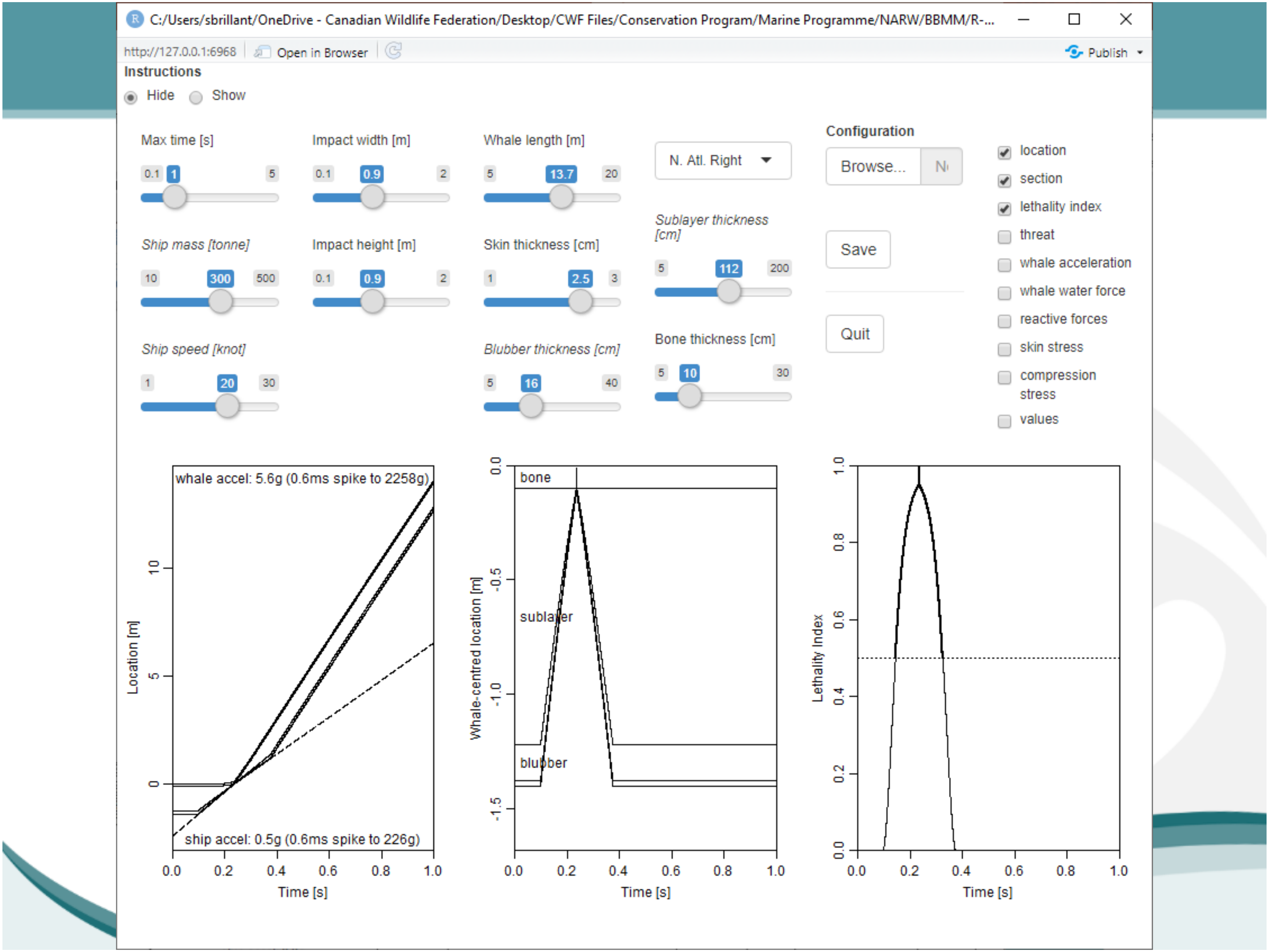

45 tonne fishing boat
311 tonne ship
30000 tonne ship
Compression Stress [MPa]
P(lethal)
Vessel Speed [knot]
τ_{50}
0.85
0.83
0.69
4.5 - 4.7
6.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
2
4
6
8
10
12
0
0.3
0.6
0.7
0.8
0.9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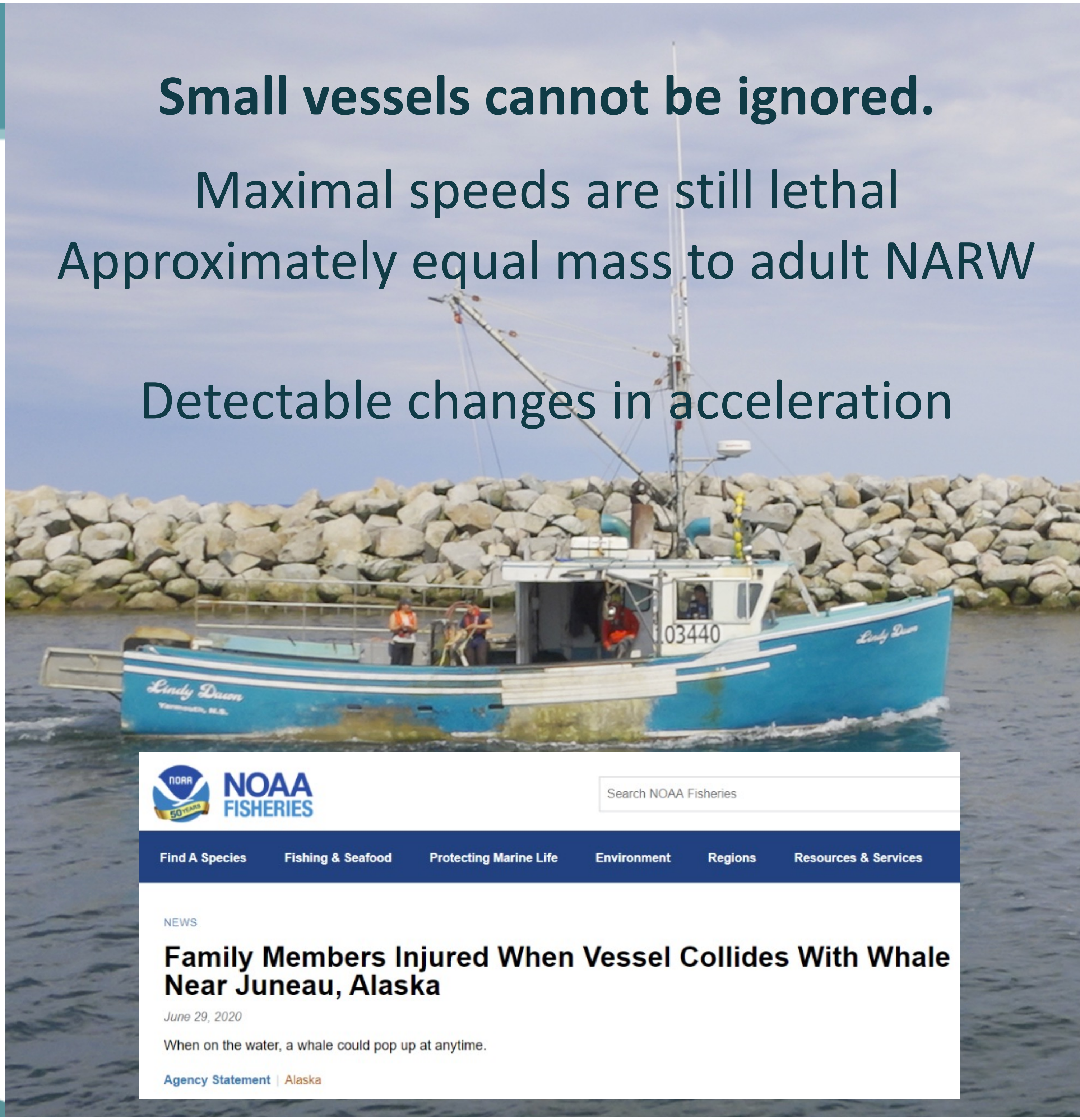
Open in Browser
Publish
Instructions
Hide
Show
Max time [s]
0.1
1
5
Impact width [m]
0.1
0.9
2
Whale length [m]
5
13.7
20
N. Atl. Right
Configuration
Browse...
location
section
lethality index
threat
whale acceleration
whale water force
reactive forces
skin stress
compression stress
values
Ship mass [tonne]
10
300
500
Impact height [m]
0.1
0.9
2
Skin thickness [cm]
1
2.5
3
Sublayer thickness [cm]
5
112
200
Save
Quit
Ship speed [knot]
1
20
30
Blubber thickness [cm]
5
16
40
Bone thickness [cm]
5
10
30
whale accel: 5.6g (0.6ms spike to 2258g)
ship accel: 0.5g (0.6ms spike to 226g)
Location [m]
Time [s]
bone
sublayer
blubber
Whale-centred location [m]
Time [s]
Lethality Index
Time [s]

Small vessels cannot be ignored.

Maximal speeds are still lethal

Approximately equal mass to adult NARW

Detectable changes in acceleration



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NEWS

Family Members Injured When Vessel Collides With Whale Near Juneau, Alaska

June 29, 2020

When on the water, a whale could pop up at anytime.

Agency Statement | Alaska

Small vessels cannot be ignored.

For large vessels, there is no safe speed.

<u>10 knot limits will not solve whale lethality</u>

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ARTICLE

Marine Mammal Science

Assessing the lethality of ship strikes on whales using simple biophysical models

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Abstract

Studies of ship strikes on whales often focus on large vessels (>20 m), with attention to their speeds and the resulting risk of lethality. Smaller coastal vessels also co-occur with whales, resulting in collisions that merit study. To cast light on injuries caused by vessels of all sizes, we used knowledge of right whale anatomy and Newtonian mechanics to construct simple models that predict the mechanical stresses experienced by whales during collisions. By comparing our predictions with published models and with data from ship strikes on various whale species, we developed a model for lethal injury as a func-

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Florida FWCC NOAA permit 18786

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Max weight = 71 tonnes

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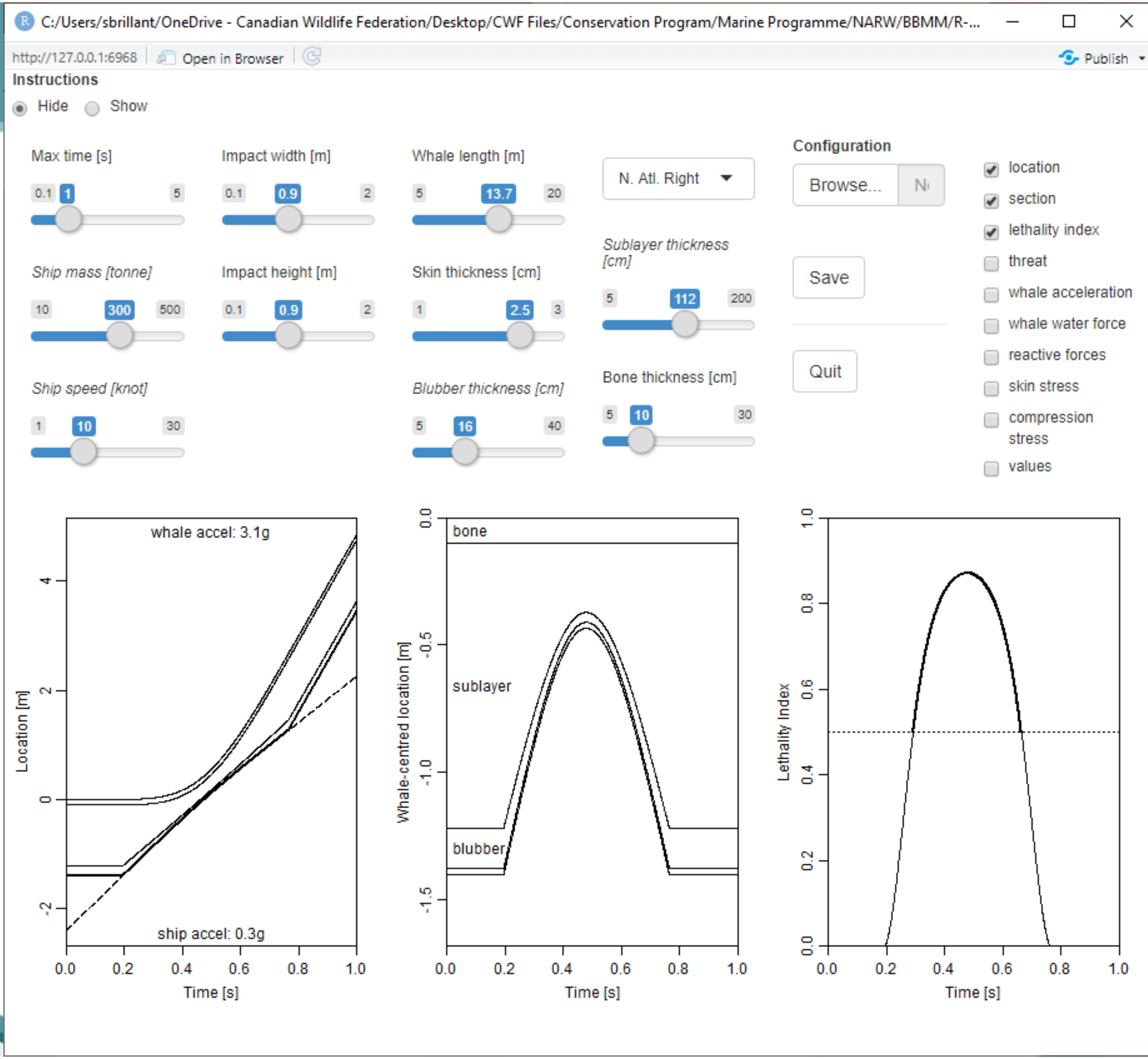
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Open in Browser
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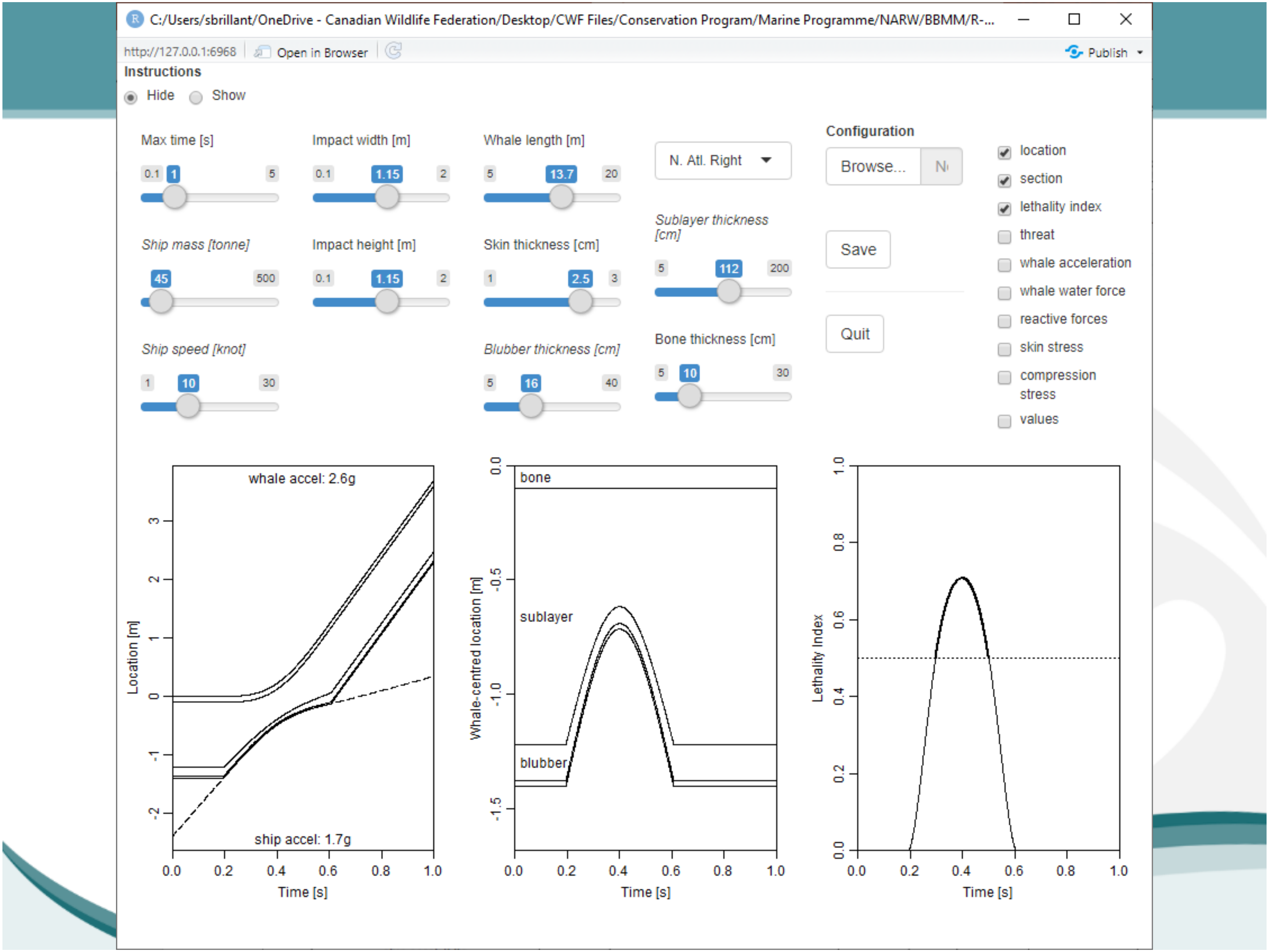
Instructions
Hide
Show
Max time [s]
0.1
1
5
Impact width [m]
0.1
0.9
2
Whale length [m]
5
13.7
20
N. Atl. Right
Configuration
Browse...
location
section
lethality index
threat
whale acceleration
whale water force
reactive forces
skin stress
compression stress
values
Ship mass [tonne]
10
300
500
Impact height [m]
0.1
0.9
2
Skin thickness [cm]
1
2.5
3
Sublayer thickness [cm]
5
112
200
Save
Quit
Ship speed [knot]
1
10
30
Blubber thickness [cm]
5
16
40
Bone thickness [cm]
5
10
30
whale accel: 3.1g
ship accel: 0.3g
Location [m]
Time [s]
bone
sublayer
blubber
Whale-centred location [m]
Time [s]
Lethality Index
Time [s]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Whale length [m]
N. Atl. Right
Configuration
Browse...
location
section
lethality index
threat
whale acceleration
whale water force
reactive forces
skin stress
compression stress
values
Ship mass [tonne]
Impact height [m]
Skin thickness [cm]
Sublayer thickness [cm]
Save
Quit
Ship speed [knot]
Blubber thickness [cm]
Bone thickness [cm]
whale accel: 2.6g
ship accel: 1.7g
Location [m]
Time [s]
bone
sublayer
blubber
Whale-centred location [m]
Lethality Index