Confronting ecosystem tipping points in ocean conservation and management: the predictable and the unpredictable

Jameal Samhouri
NOAA Northwest Fisheries Science Center
Seattle, WA

Take-home messages

1. Tipping points are common, but will be difficult to predict.

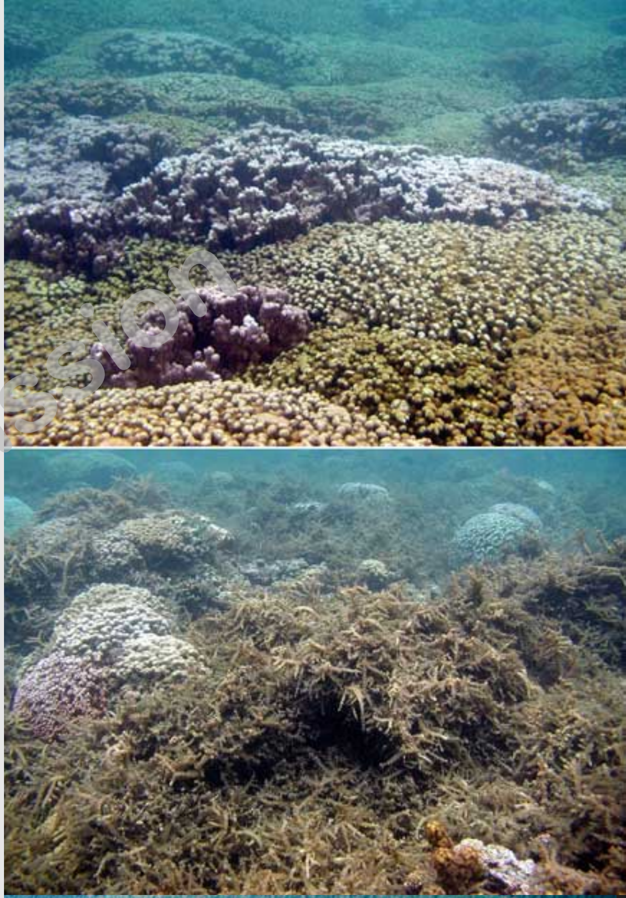
2. Develop a variety of biological models, including those that are mechanistic, spatial, and inherently nonlinear.

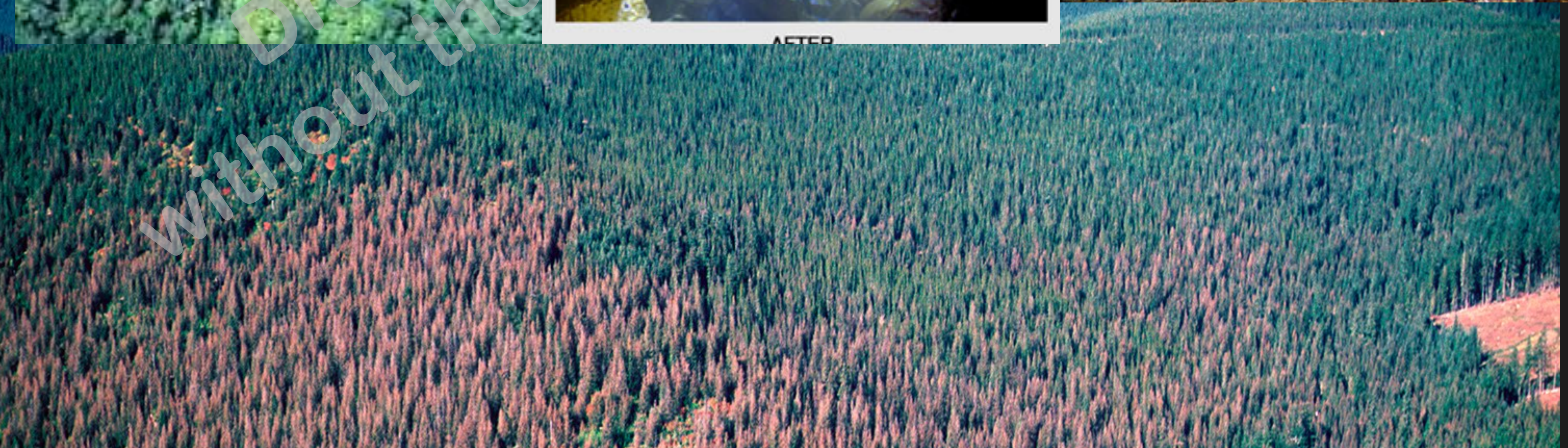
3. Design ecosystem-based management approaches robust to a range of potential futures.

Ecosystem Tipping Points

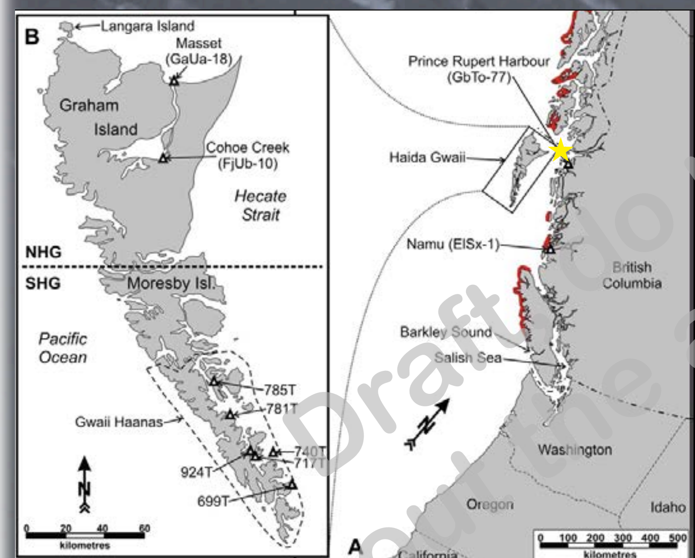
When incremental changes in environmental conditions or human activities result in large, and sometimes abrupt, changes in ecosystem structure, function, and often, benefits to people

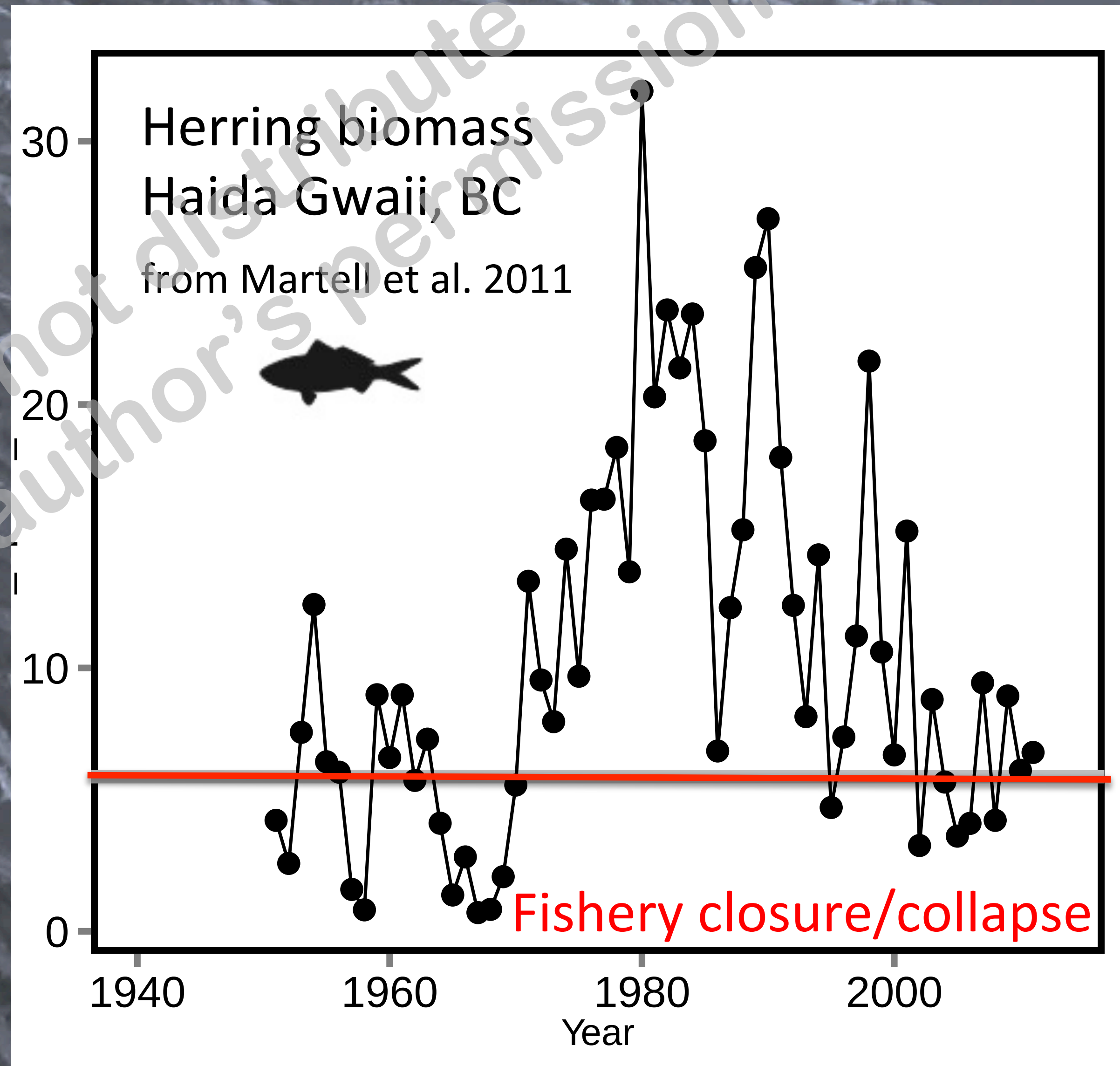
AFTER



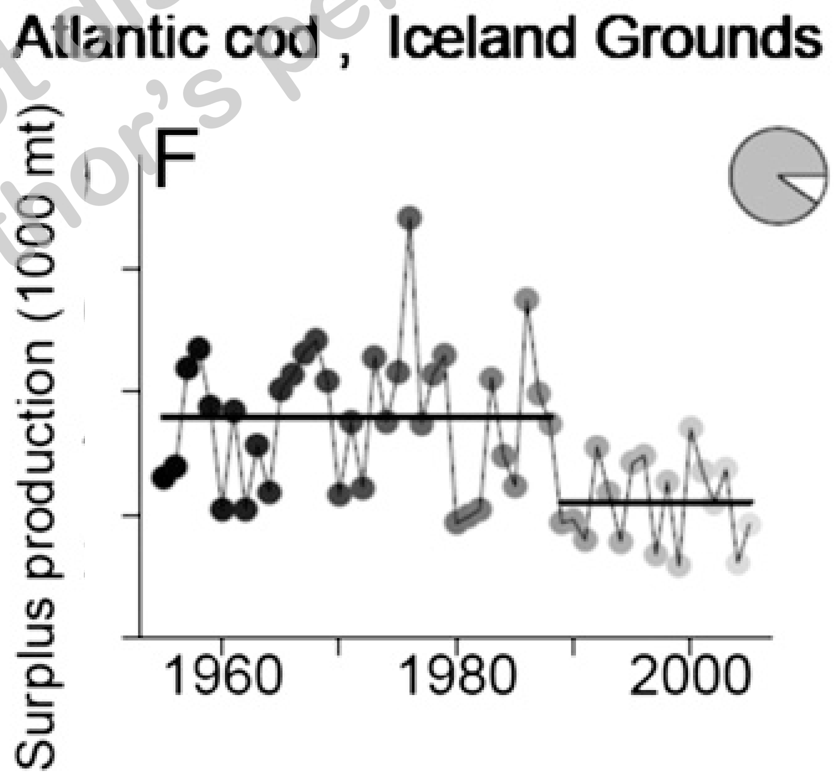


Fishery collapses as tipping points



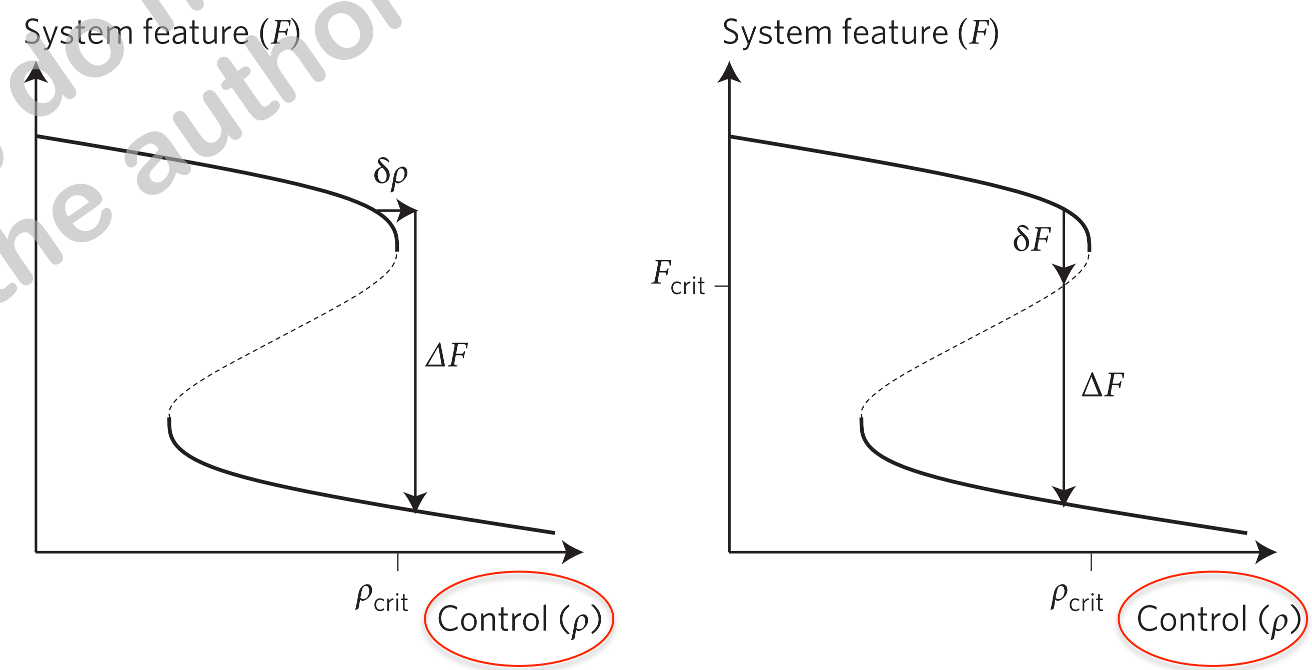


Productivity regime shifts in marine fish stocks represent tipping points



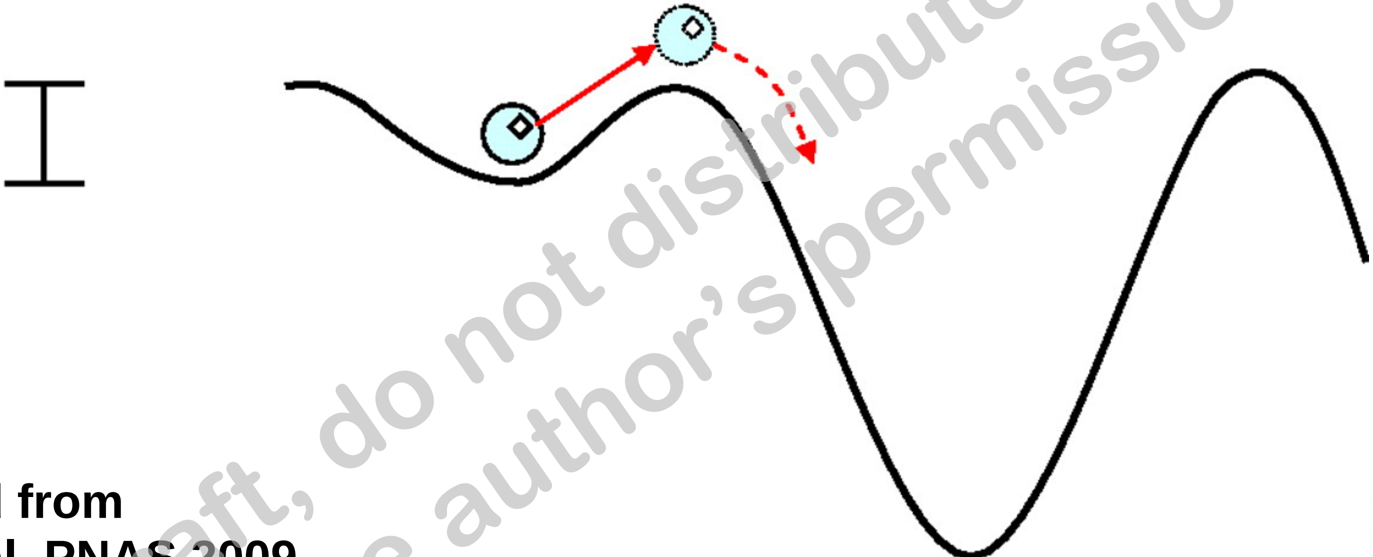
Vert-pre et al. 2013

Inherently nonlinear dynamics can produce alternate ecosystem states



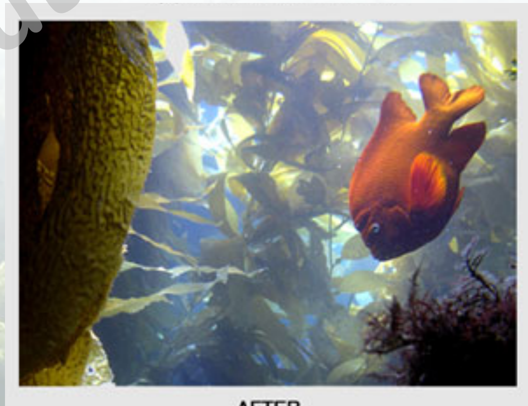
Lenton 2011

Recovery may be difficult and slow



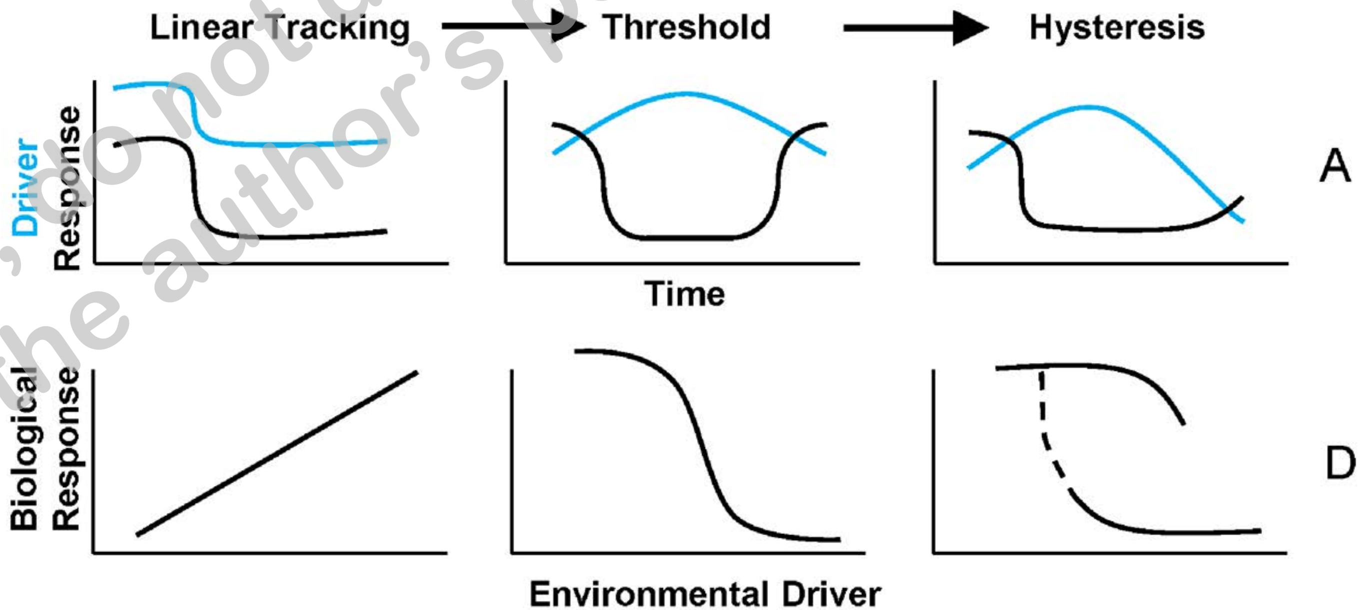
Modified from
Ling et al. PNAS 2009

Kelp bed



Sea urchin barren

Tipping and recovery depend on control processes



Bestelmeyer et al. 2011

1. Are control processes nonlinear?

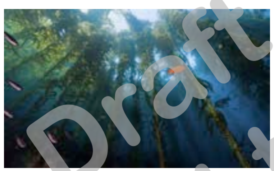
2. How common are tipping points?

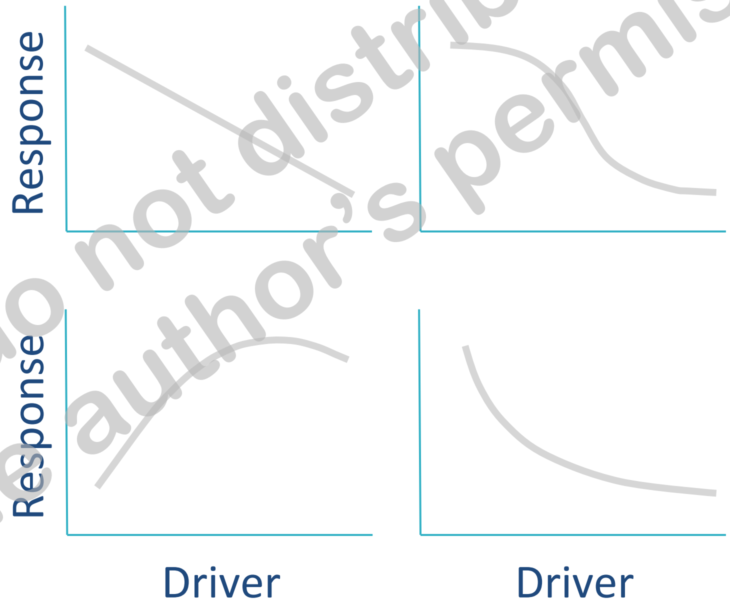
3. How long do recoveries require?

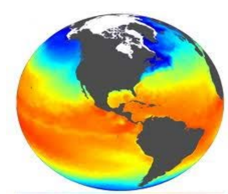
www.oceantippingpoints.org

OUR PARTNERS

Meta-analysis of ecological thresholds in the open ocean

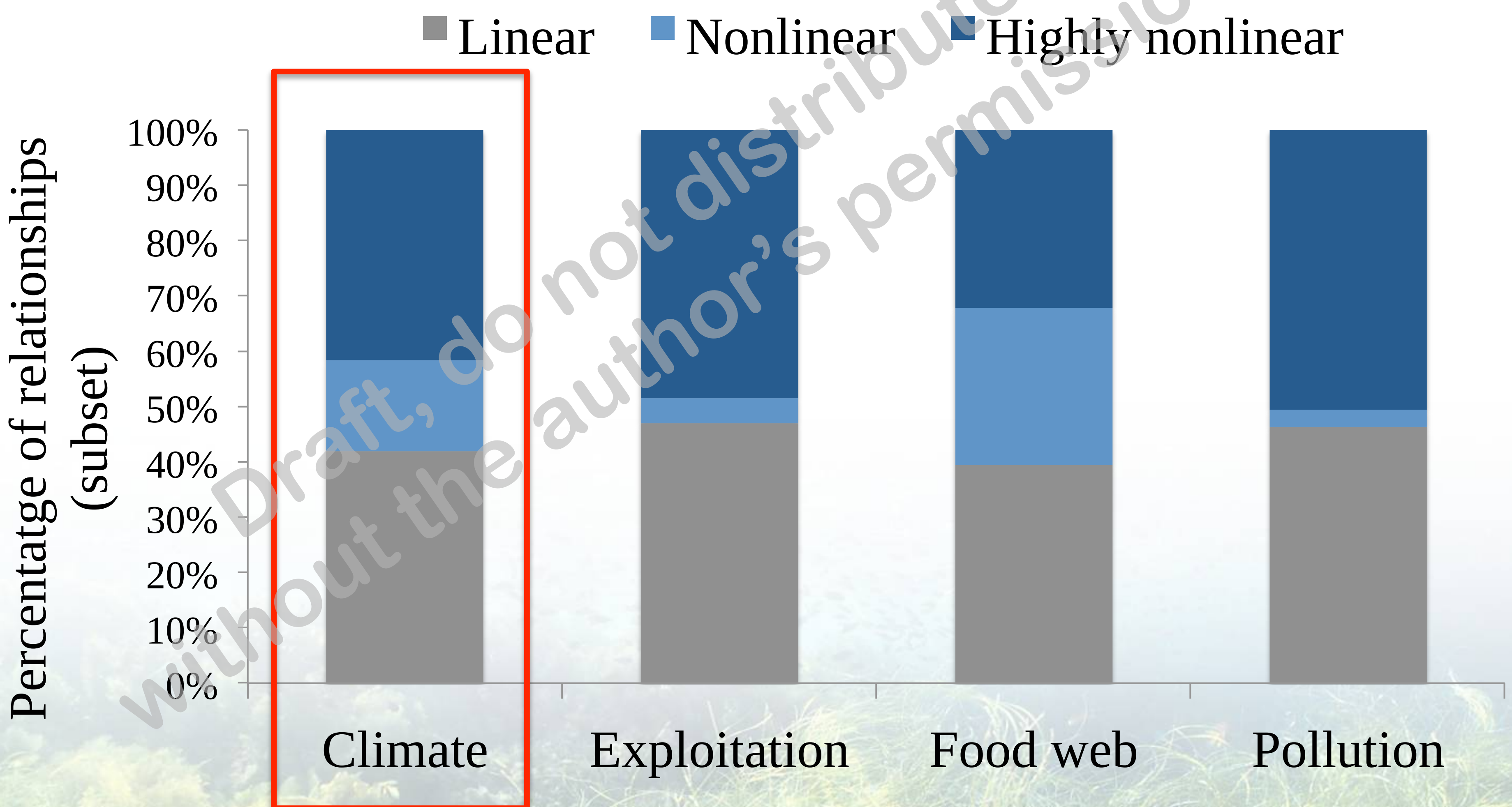






Hunsicker et al. Ecological Applications. Characterizing driver-response relationships in marine pelagic ecosystems for improved ocean management. *In press*

Half of the studied relationships between drivers and ecosystem components in the open ocean are nonlinear



Hunsicker et al. Ecological Applications. Characterizing driver-response relationships in marine pelagic ecosystems for improved ocean management. *In press*

1. Are control processes nonlinear?

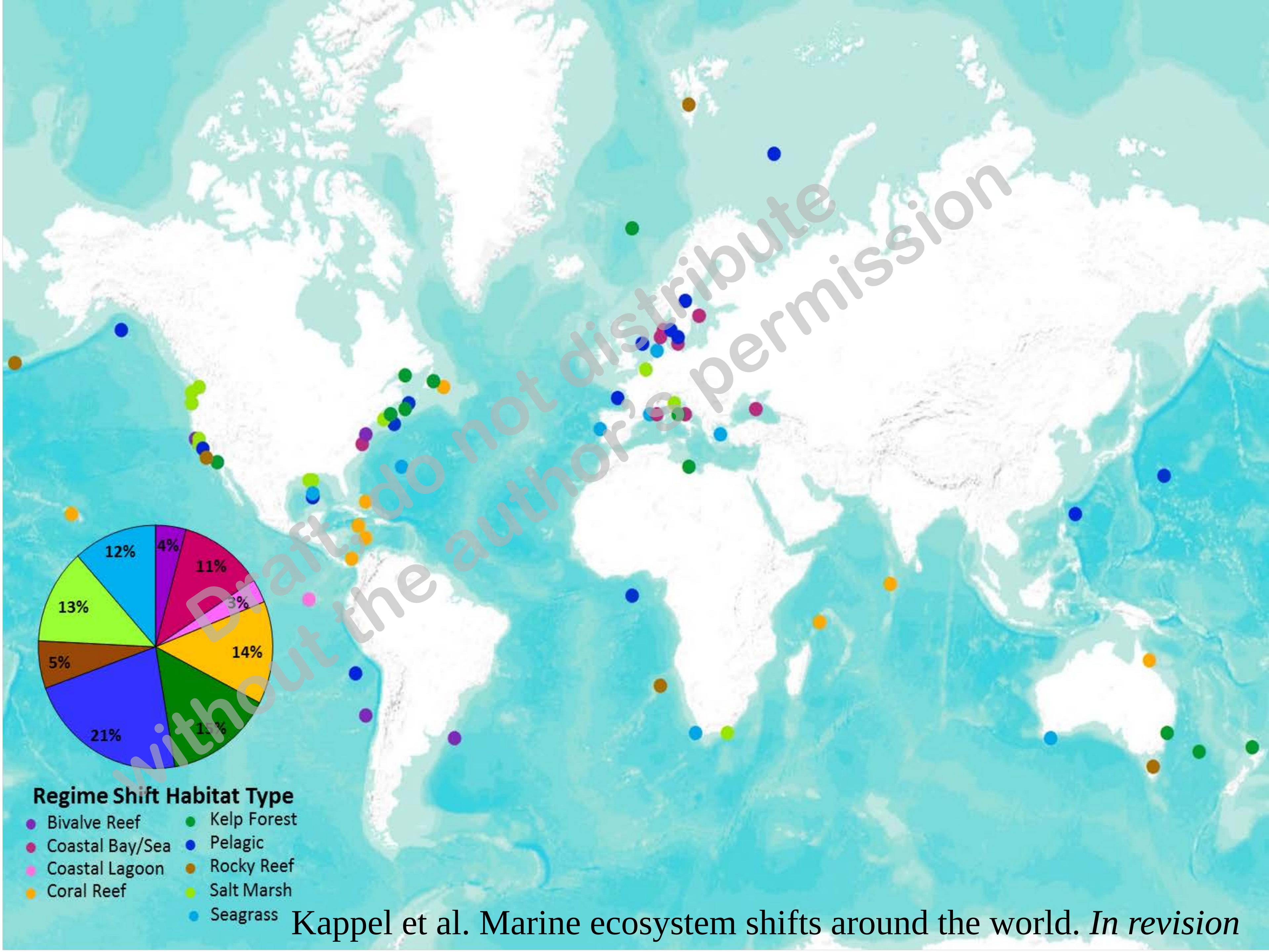
2. How common are tipping points?

3. How long do recoveries require?

www.oceantippingpoints.org

OUR PARTNERS

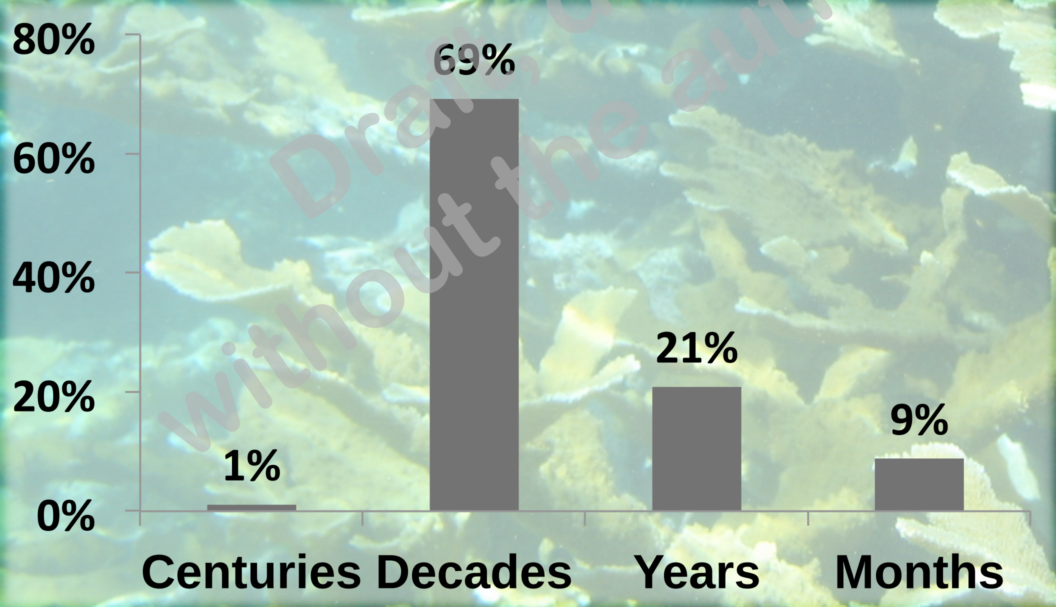
UCSB NCEAS NOAA CENTER FOR OCEAN SOLUTIONS EDF ENVIRONMENTAL DEFENSE FUND GORDON AND BETTY MOORE FOUNDATION



Kappel et al. Marine ecosystem shifts around the world. *In revision*

Ecosystem recoveries tend to take decades or more

Kappel et al. Marine ecosystem shifts around the world. *In revision*



Major Findings

- 91 marine regime shifts have been documented from 9 major ecosystem types and all ocean basins.

- Most marine ecosystem shifts persist for decades

- Climate is a key driver of most shifts, but acts in concert with local drivers like fishing, nutrient addition

- History and feedbacks in persistence of regime shifts and effects on eco. services remain poorly documented.

- More attention on how drivers may alter species interactions and lead to regime shifts.

Kappel et al. Marine ecosystem shifts around the world. *In revision*

Marine ecosystem dynamics are often driven by nonlinear processes characterized by tipping points, which require long recoveries

Accurate prediction of ecosystem tipping points requires mechanistic understanding

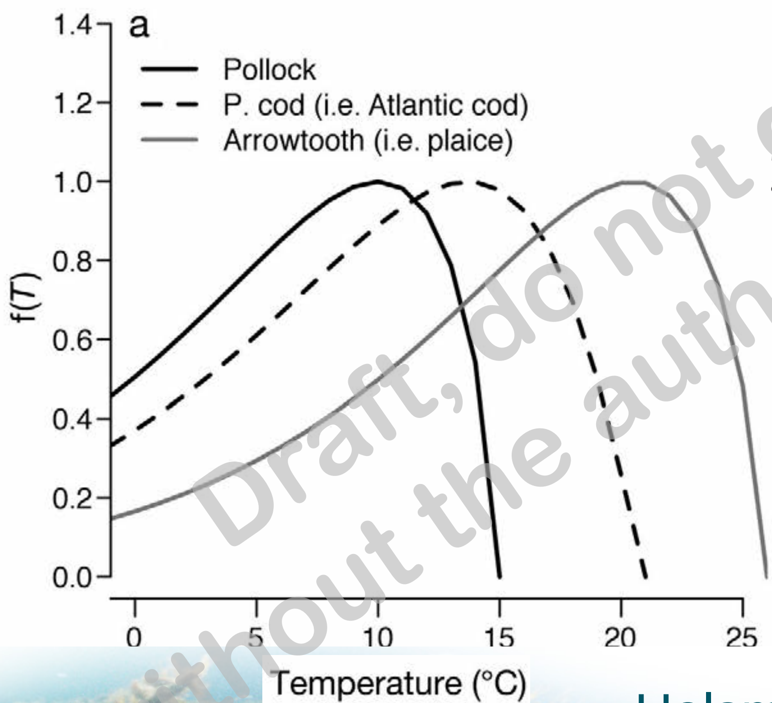
Reviews in Fish Biology and Fisheries **8**, 285–305 (1998)

When do environment–recruitment correlations work?

RANSOM A. MYERS

(obligatory RAM slide)

Fully coupled mechanistic biophysical models are within reach



Impacts of climate change on marine ecosystem production in societies dependent on fisheries

M. Barange[1*], G. Merino[1,2], J. L. Blanchard[3], J. Scholtens[4], J. Harle[5], E. H. Allison[6], J. I. Allen[1], J. Holt[5] and S. Jennings[7,8]

Holsman and Aydin 2015

Early warning indicators offer promise but should be used cautiously where mechanisms are poorly understood

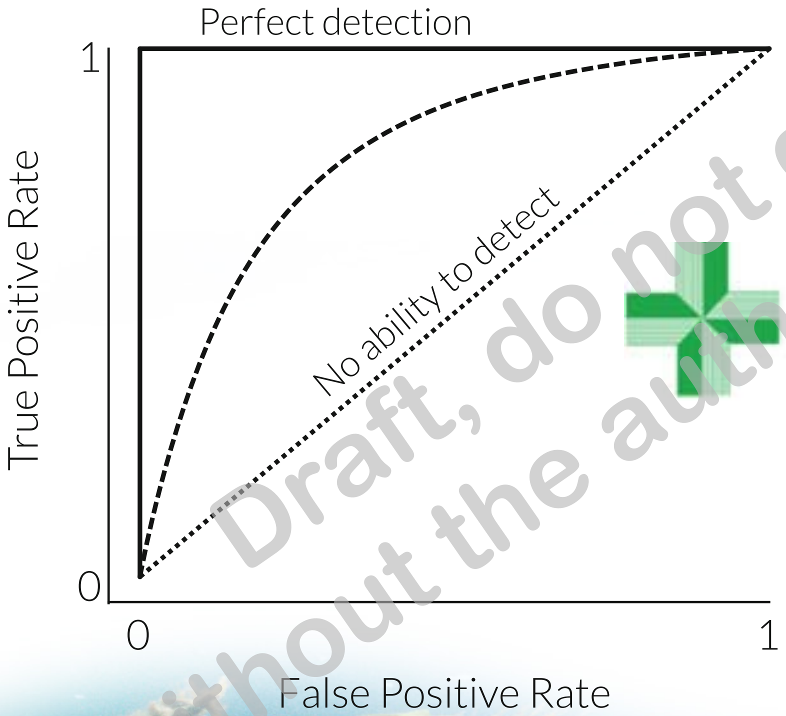
Table 1 | Early warning indicators of approaching bifurcation points and tests thereof.

Phenomenon	Indicator	System	Data Source	Signal	Reference(s)
Critical slowing down	Increasing autocorrelation, AR(1) coefficient	Climate	Models	+	8, 10, 12, 53
			Palaeorecord	+	10, 12, 53
				0	12, 13
		Ecological	Models	+	44
	Increasing return time from perturbations	Ecological	Models	+	39, 40, 45, 51
			Lab experiments	+	6, 52
	Increasing DFA exponent	Climate	Models	+	9, 11, 12
			Palaeorecord	+	9, 12
				−	12
	Spectral reddening	Climate	Models	+	7
		Ecological	Model	0	79
	Increasing spatial correlation	Ecological	Models	+	47
			Lab experiments	+	52
Increased variability	Increasing variance	Climate	Models	+	12
				0	12
			Palaeorecord	+	12
				0	13
				−	12
		Ecological	Models	+	43–45, 79
			Lab experiments	+	52
	Increasing spatial variance	Ecological	Model	+	48
			Data	+	49
			Lab experiments	+	52
Skewed responses	Increasing skewness	Climate	Palaeodata	0	46
		Ecological	Model	+	44–46
			Lab experiments	+	52
	Increasing spatial skewness	Ecological	Model	+	48

'+' means indicator increased as expected; '−' means indicator decreased, contrary to expectation; '0' means there was no significant change in the indicator.

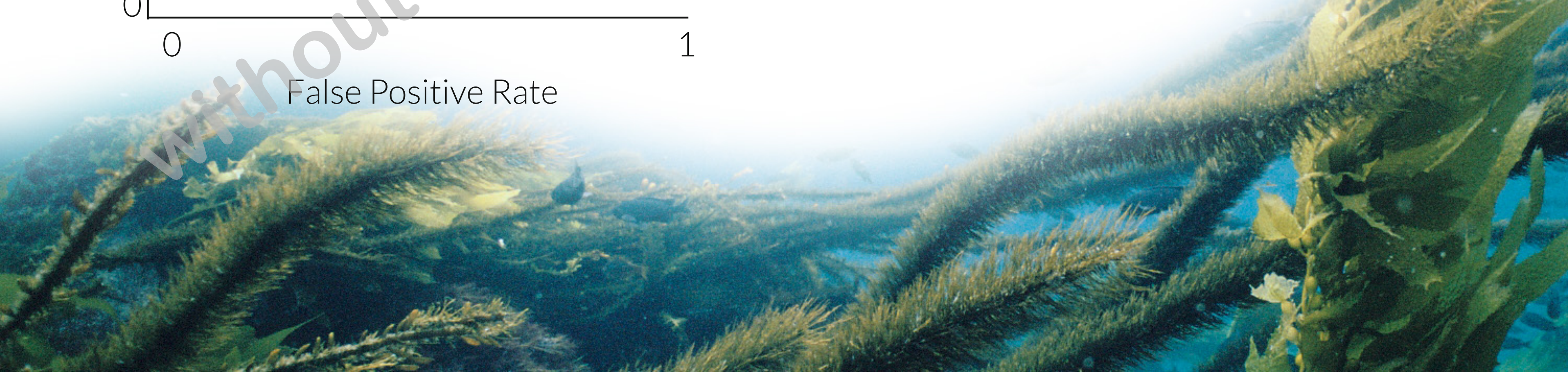
Scheffer et al. 2009
Scheffer et al. 2012
Lenton 2011

Early warning indicators offer promise but should be used cautiously where mechanisms are poorly understood



Ask Your Pharmacist

Boettinger and Hastings 2013



The predictability of surprise

Ecological Applications, 6(3), 1996, pp. 733–735

SURPRISE FOR SCIENCE, RESILIENCE FOR ECOSYSTEMS, AND INCENTIVES FOR PEOPLE[1,2]

C. S. HOLLING
Department of Zoology, University of Florida, Gainesville, Florida USA

Ecology, 89(4), 2008, pp. 952–961

UNDERSTANDING AND PREDICTING ECOLOGICAL DYNAMICS: ARE MAJOR SURPRISES INEVITABLE?

DANIEL F. DOAK,[1,11] JAMES A. ESTES,[2] BENJAMIN S. HALPERN,[3] UTE JACOB,[4] DAVID R. LINDBERG,[5] JAMES LOVVORN,[1] DANIEL H. MONSON,[6] M. TIMOTHY TINKER,[7] TERRIE M. WILLIAMS,[7] J. TIMOTHY WOOTTON,[8] IAN CARROLL,[9] MARK EMMERSON,[4] FIORENZA MICHELI,[10] AND MARK NOVAK[8]

Management and conservation in a predictably surprising ocean

<u>3 vignettes</u>

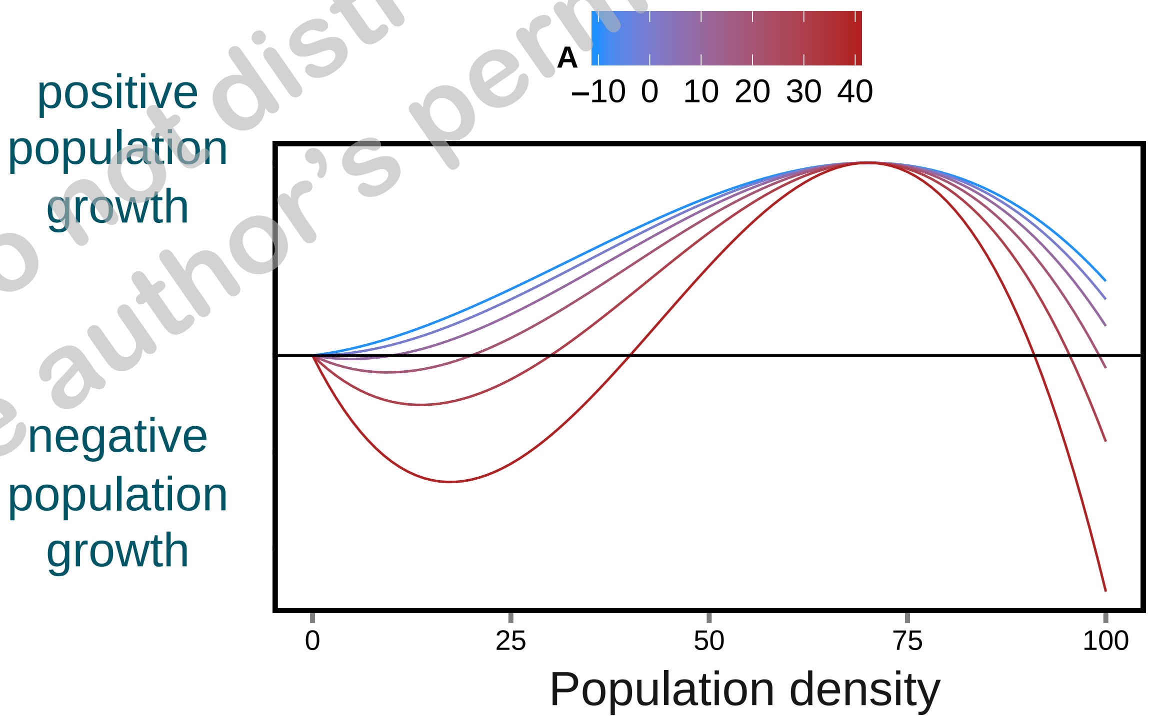
1. The value of information in a world with tipping points
2. Robust management in a stochastic, threshold-constrained world
3. Strategic recovery once tipping points are crossed

Management and conservation in a predictably surprising ocean

3 vignettes

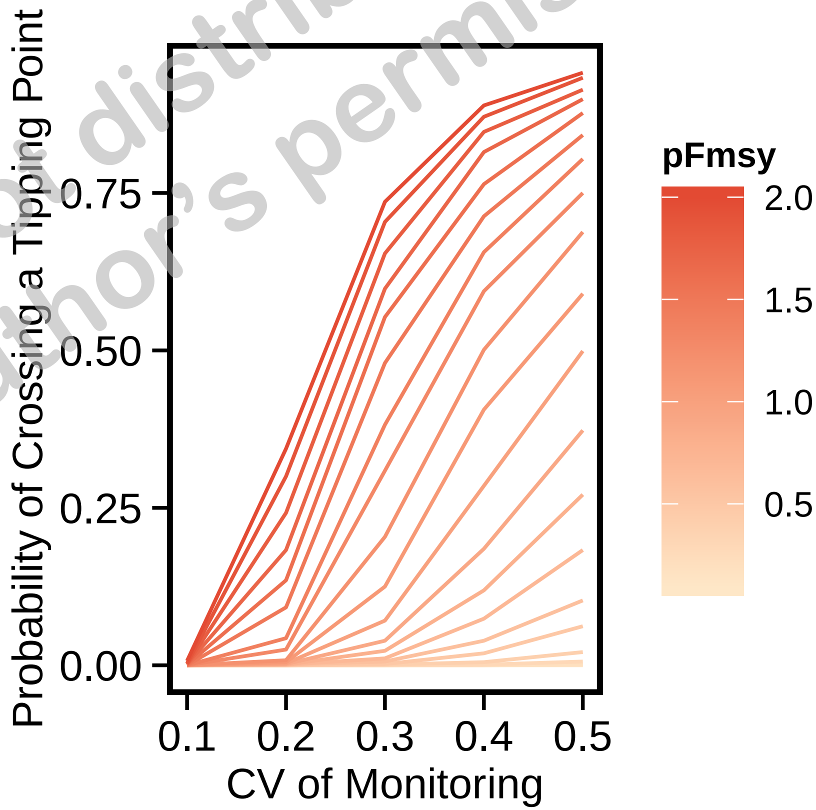
1. The value of information in a world with tipping points
2. Robust manag… stic, threshold-constrained w…
3. Strategic recov… oints are crossed

Depensatory population dynamics (Allee effects)



Stier et al. *in prep*

Potential for tipping increases the value of information



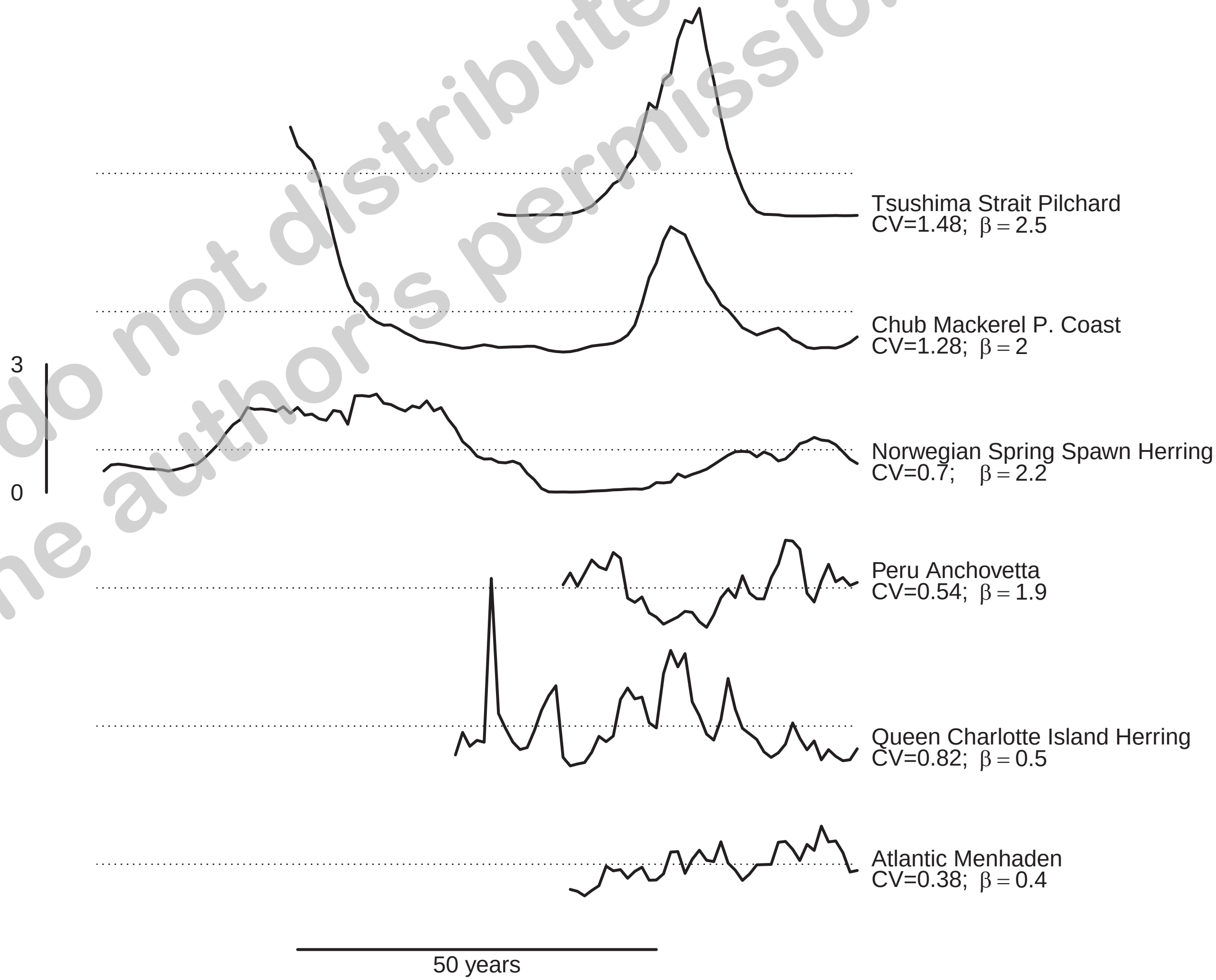
Stier et al. *in prep*

Management and conservation in a predictably surprising ocean

3 vignettes

1. The value of information in a world with tipping points
2. Robust management in a stochastic, threshold-constrained world
3. Strategic recovery once tipping points ar crossed

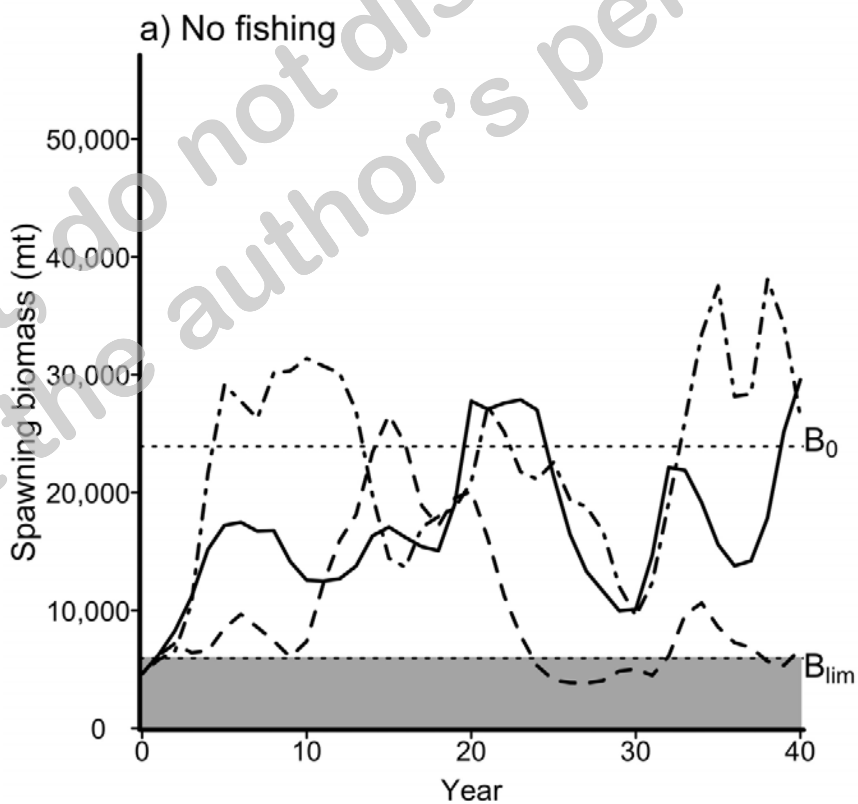
Forage fish population dynamics are inherently noisy…

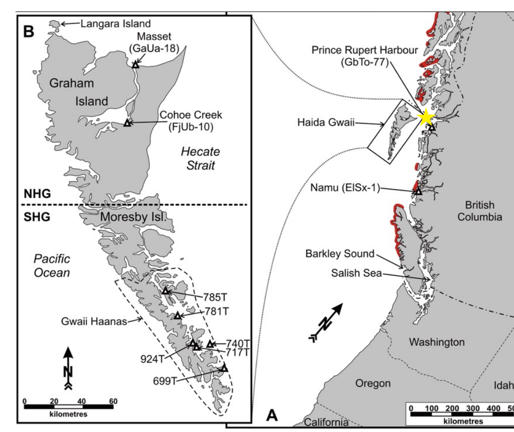


Essington et al. 2015

…and subject to collapse, even in the absence of fishing

Modeled dynamics of Pacific herring

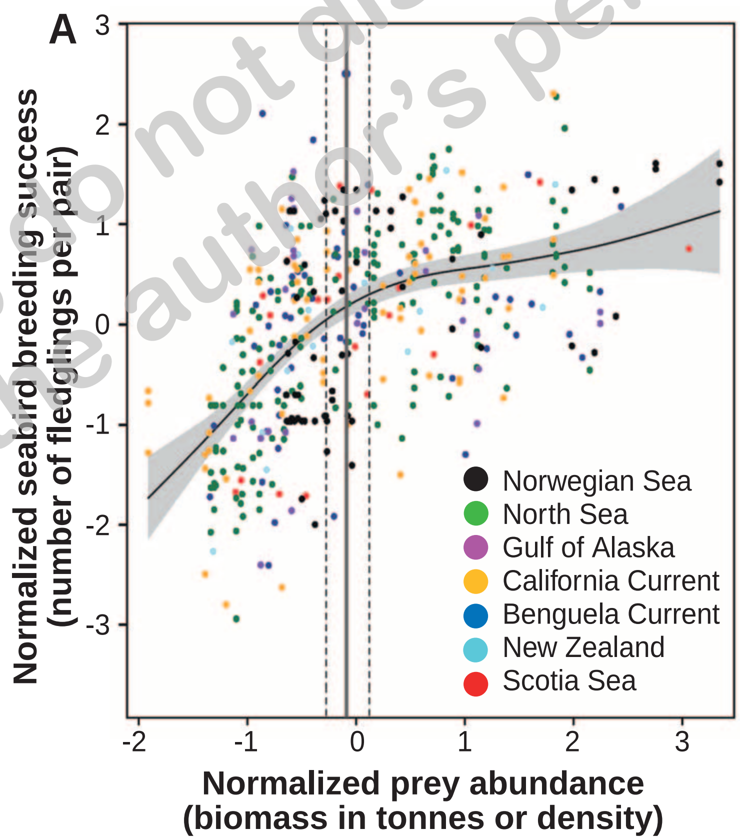


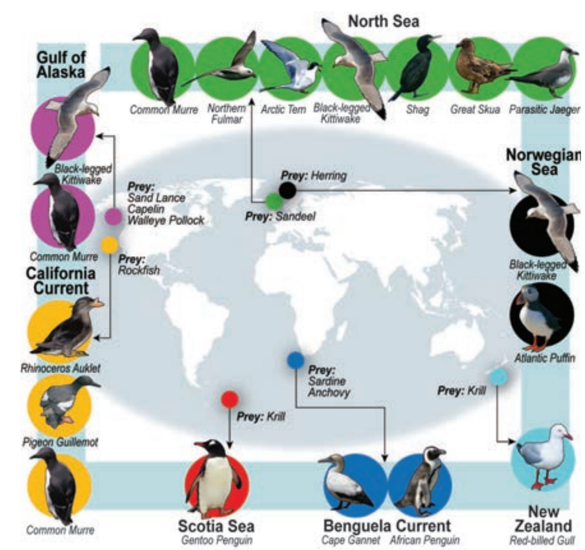


Shelton et al. 2014

These collapses matter to dependent predators

"1/3 for the birds"

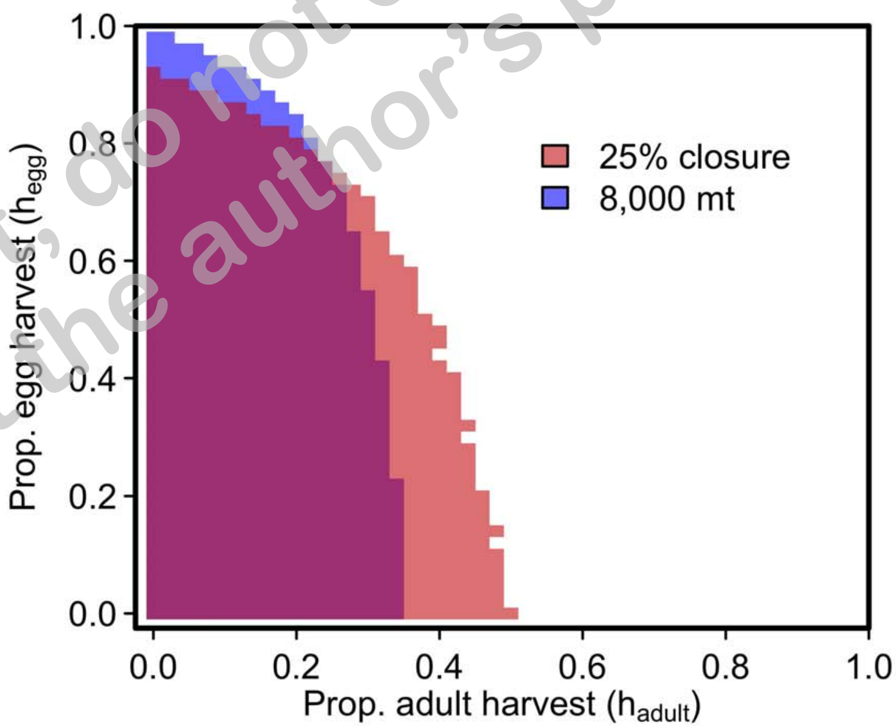


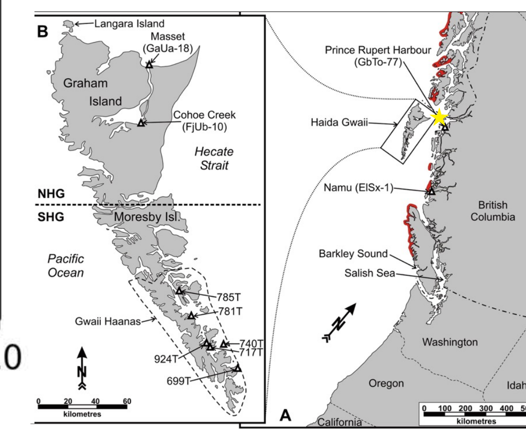


Cury et al. 2011

Some management strategies can avoid population and ecosystem tipping points

Modeled dynamics of Pacific herring





Shelton et al. 2014

Management and conservation in a predictably surprising ocean

3 vignettes

1. The value of information in a world with tipping points
2. Robust management in a stochastic, threshold-constrained world
3. Strategic recovery once tipping points are crossed

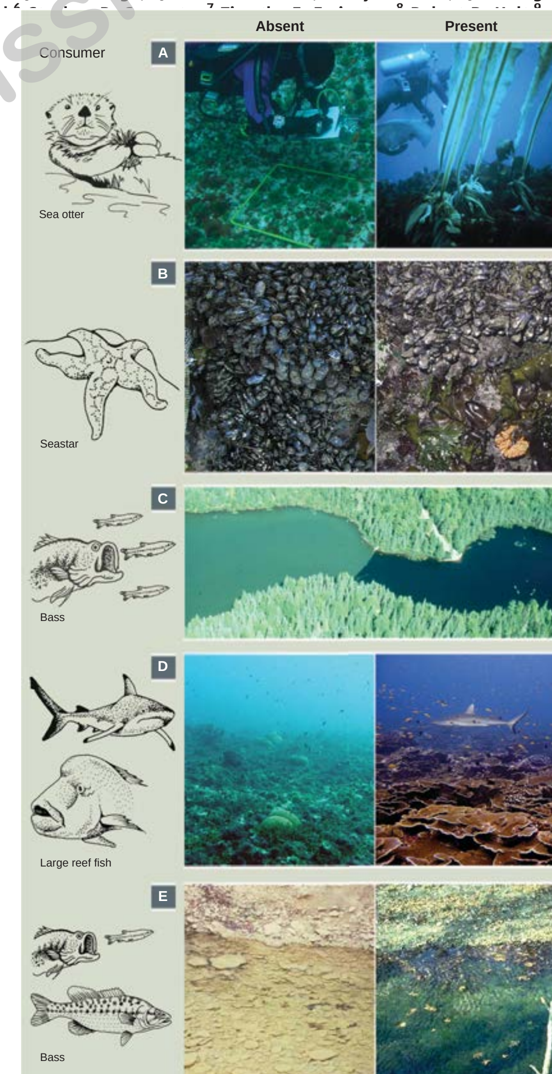
Trophic sequences of community dis-assembly lead to predictable ecosystem changes

Fishing down and through the food web

Pauly et al. 1998, Essington et al. 2006,
Branch et al. 2010

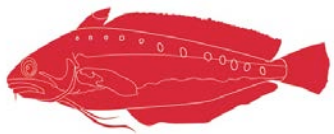
Trophic Downgrading of Planet Earth

James A. Estes,[1]* John Terborgh,[2] Justin S. Brashares,[3] Mary E. Power,[4] Joel Berger,[5]

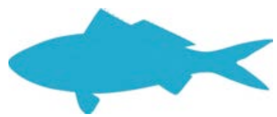


Community dis-assembly: fish down the food web

Predator

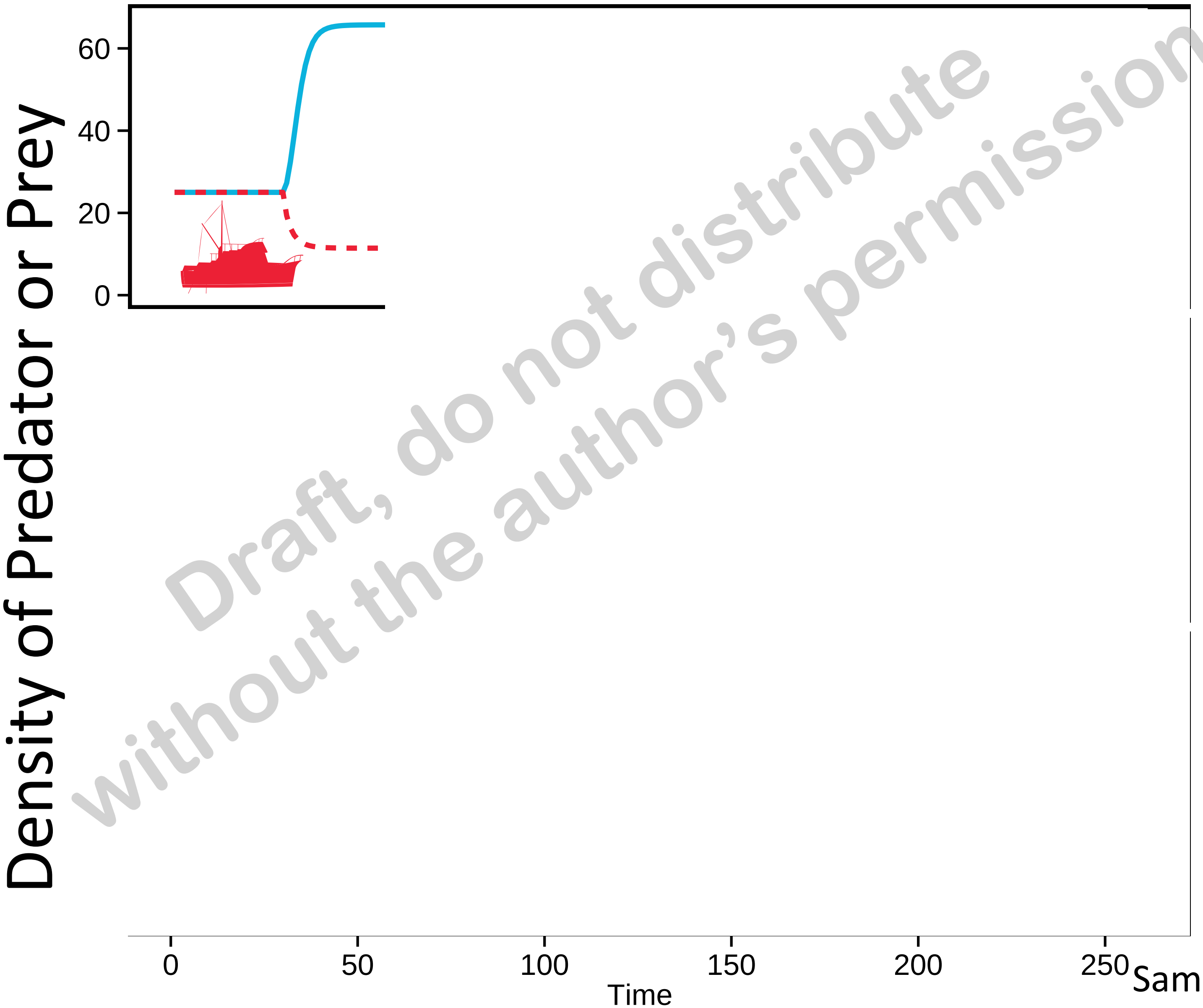


Prey

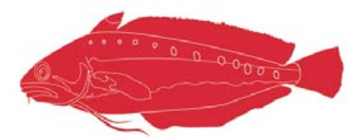


Samhouri et al. *in prep*

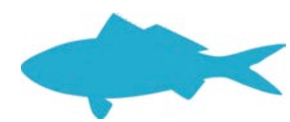
Community dis-assembly: fish down the food web



Predator

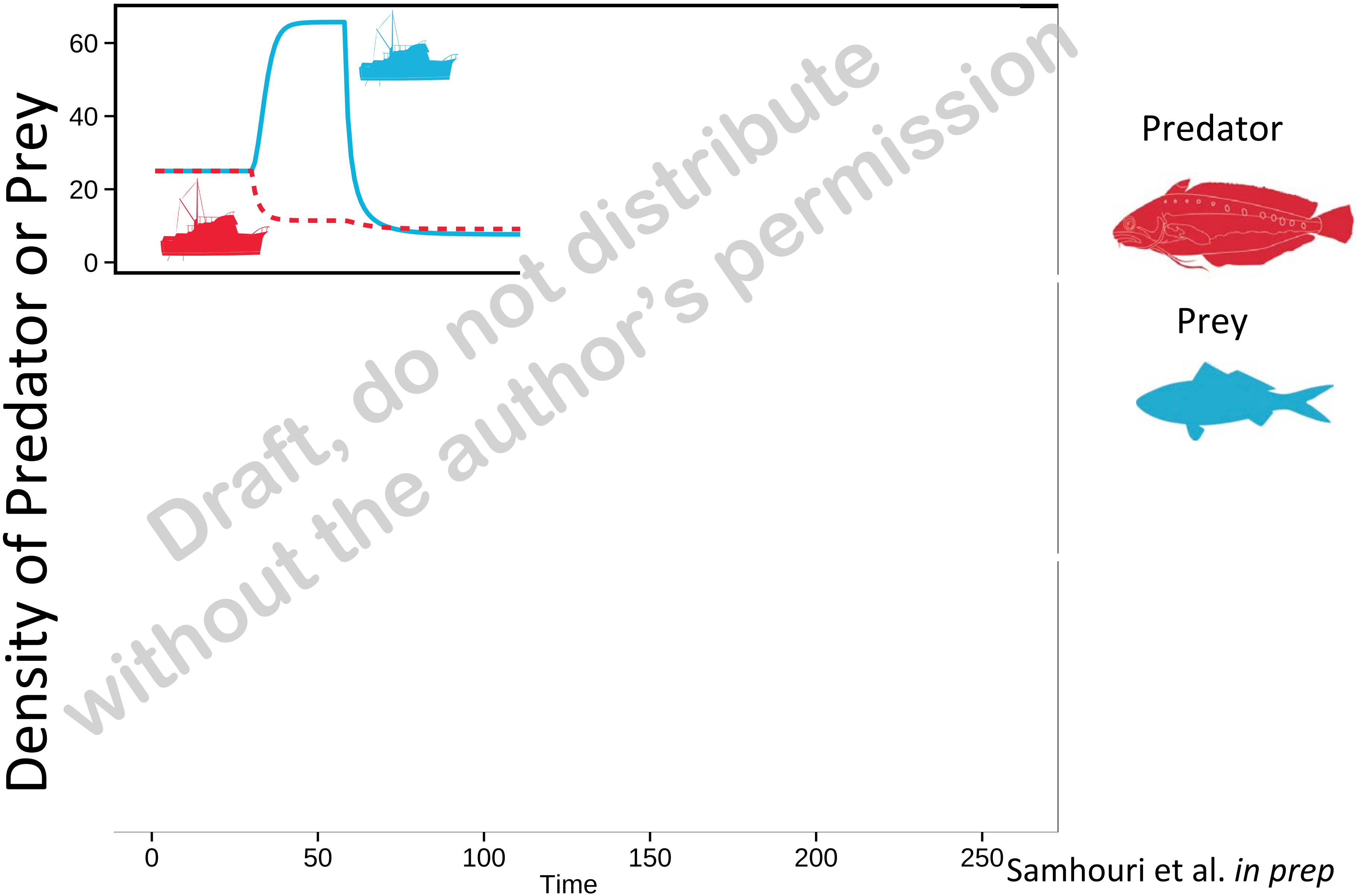


Prey



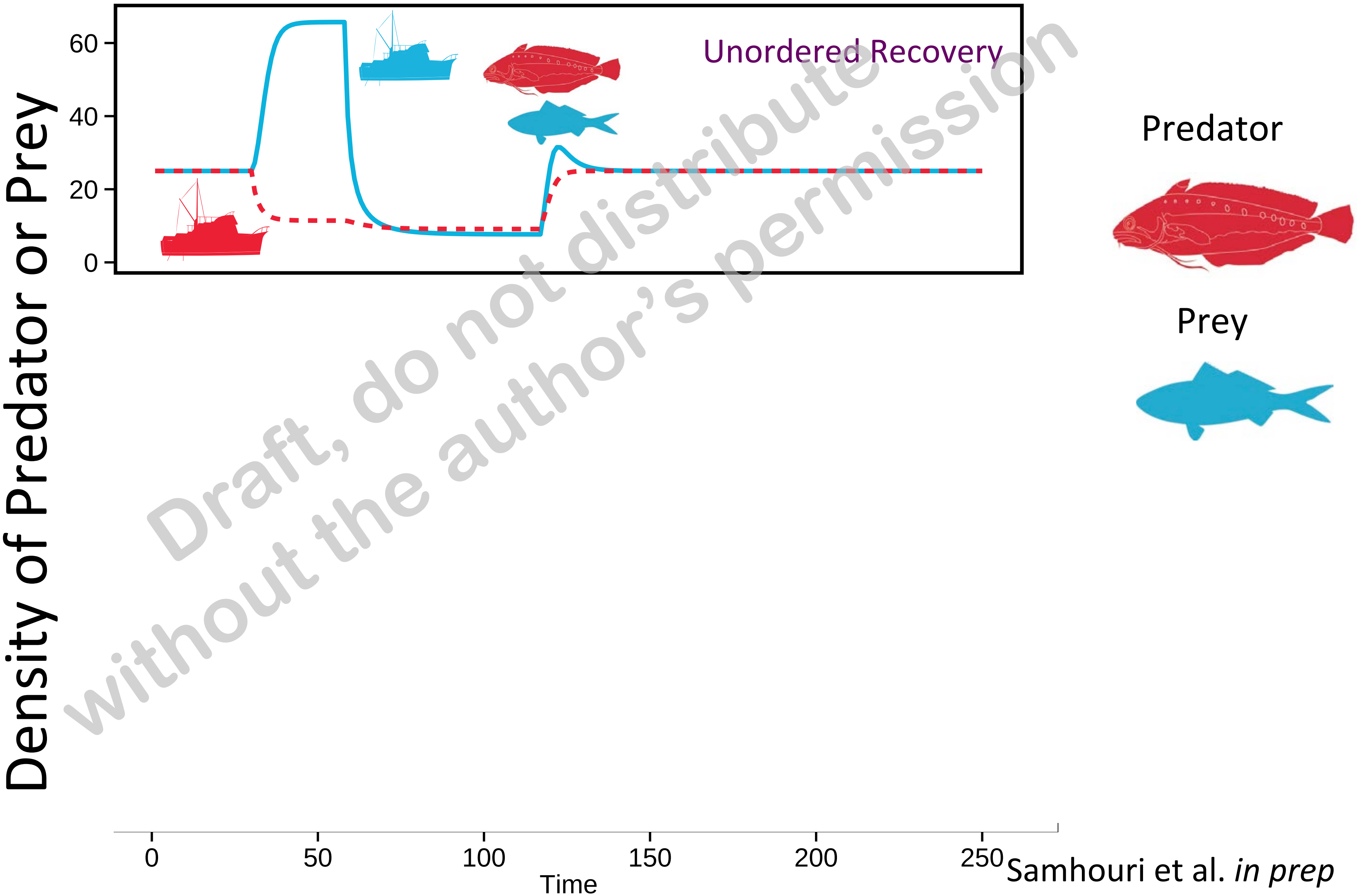
Samhouri et al. *in prep*

Community dis-assembly: fish down the food web



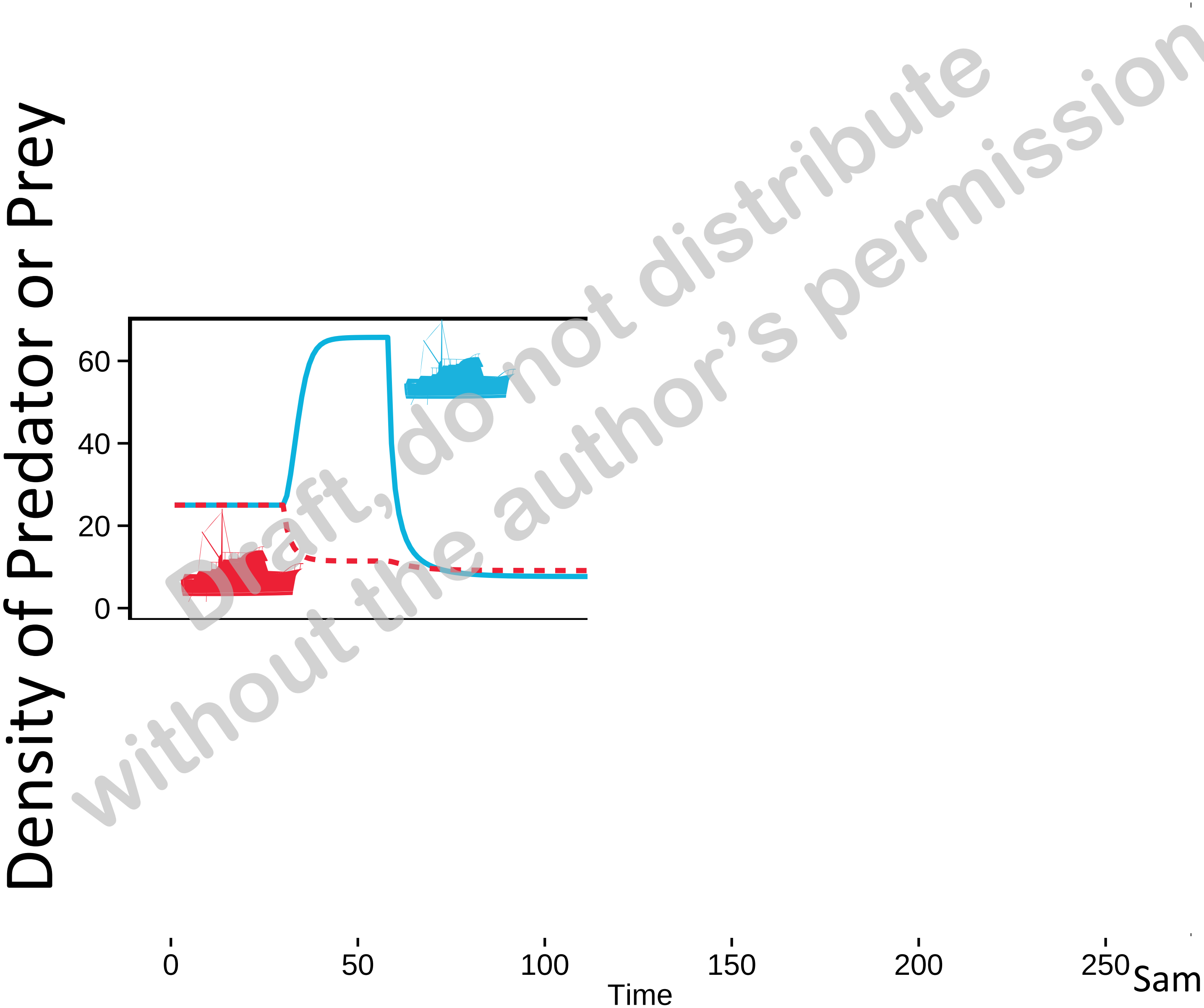
Samhouri et al. *in prep*

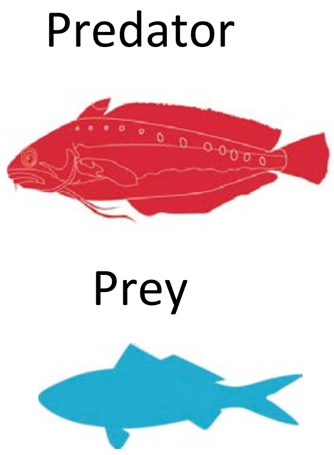
Unordered recovery: fast and direct



Samhouri et al. *in prep*

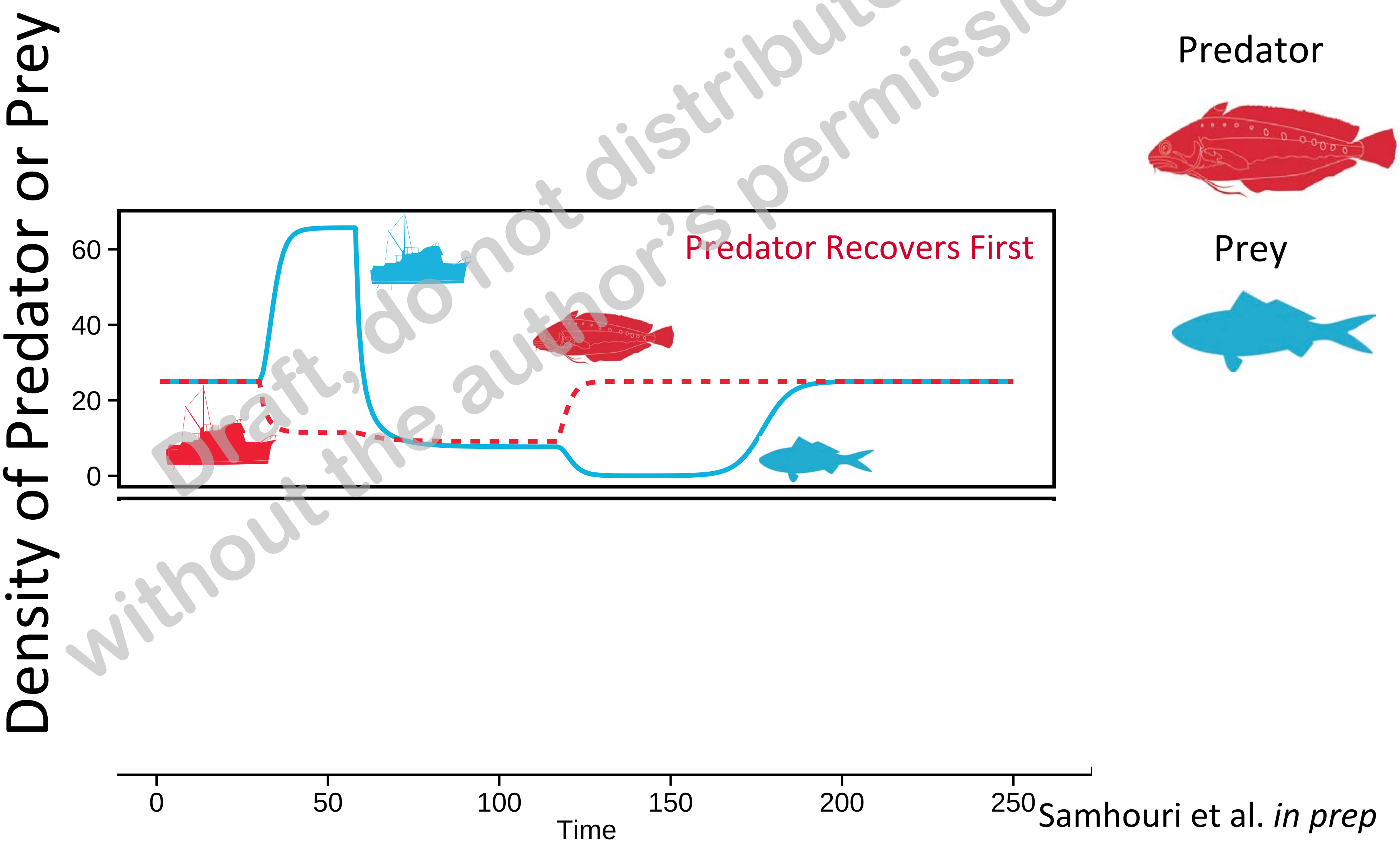
Predator first recovery





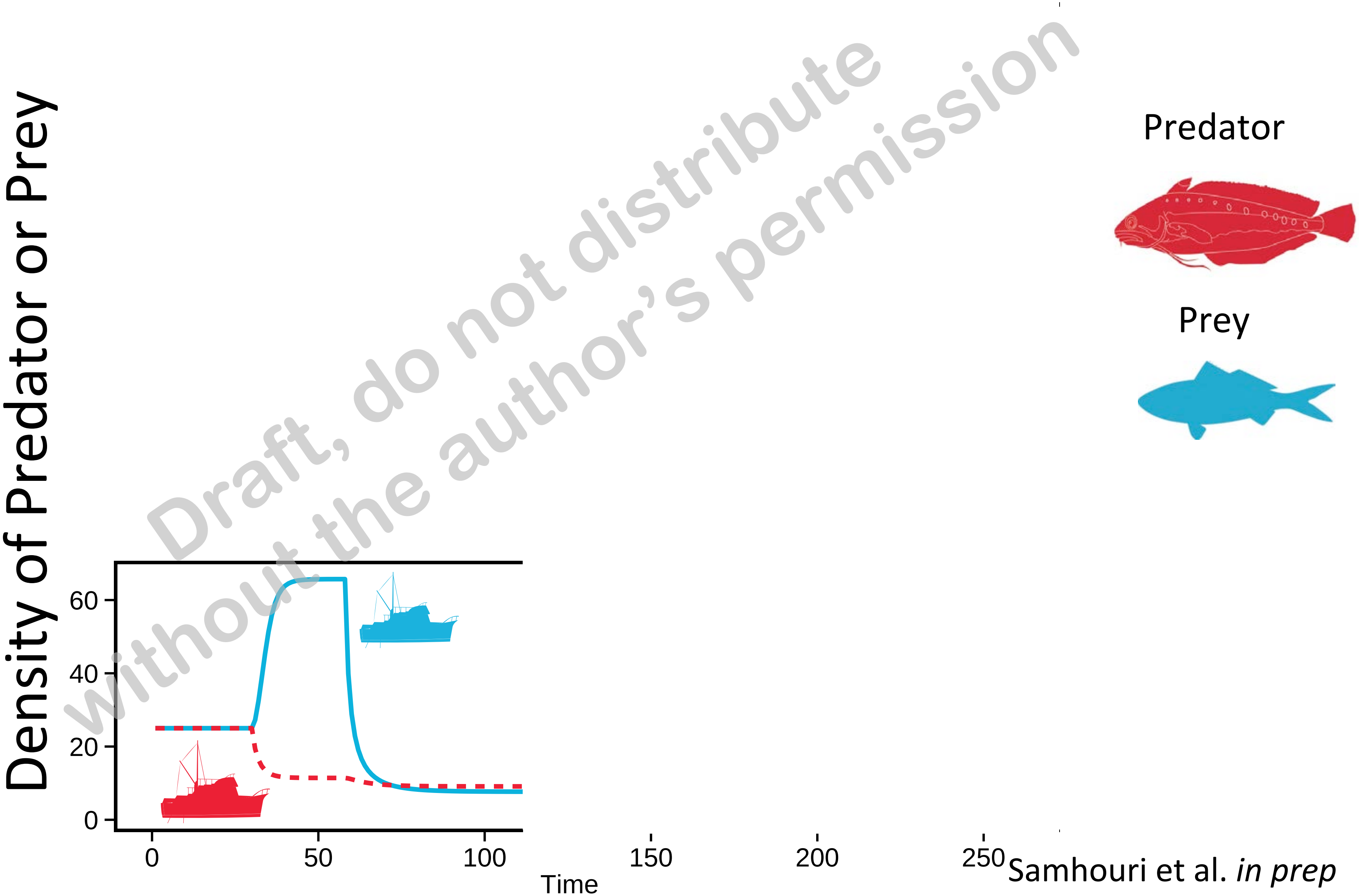
Samhouri et al. *in prep*

Predator first recovery: slow and direct



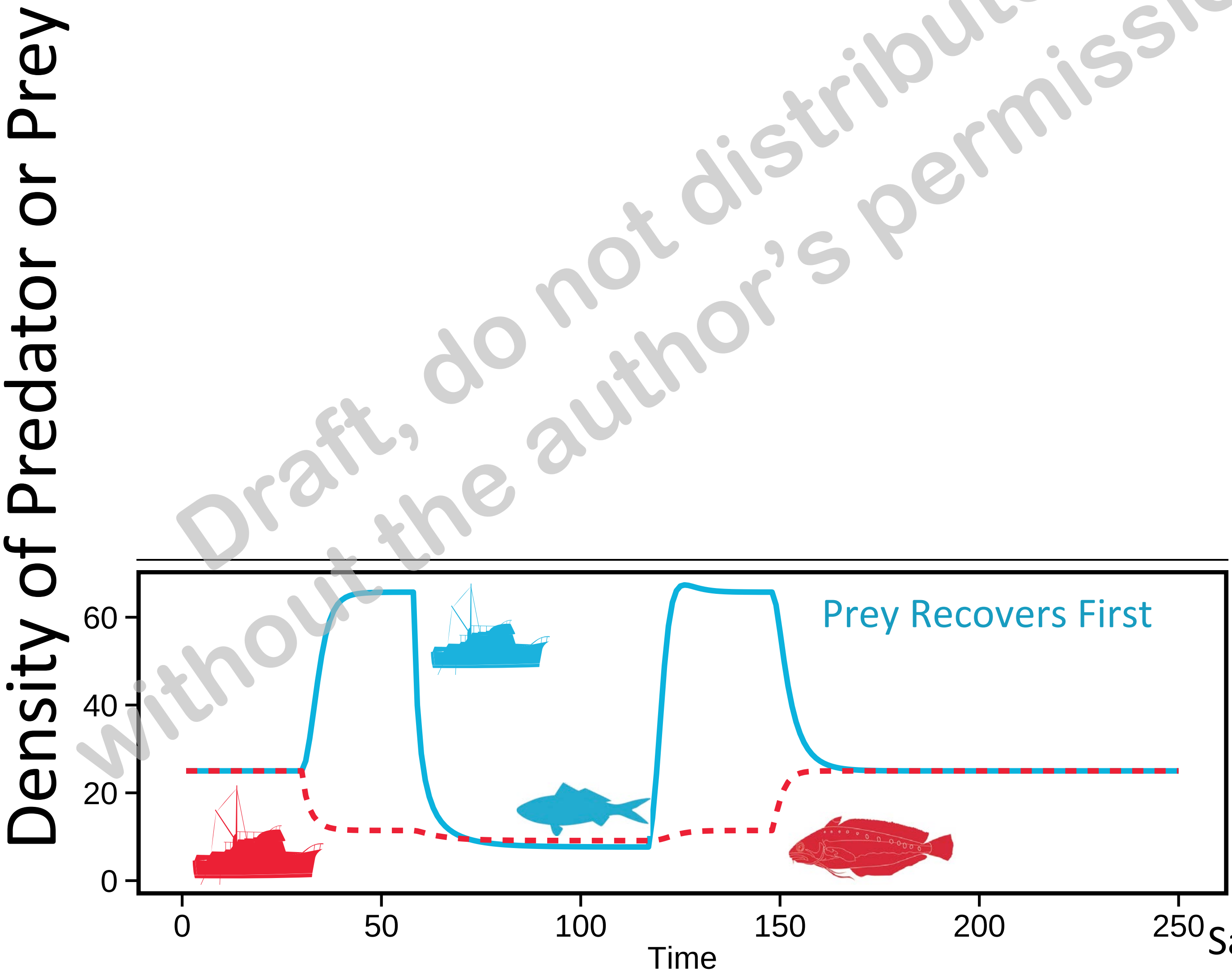
Samhouri et al. *in prep*

Prey first recovery

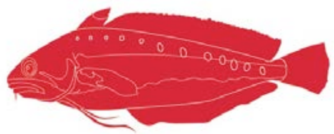


Samhouri et al. *in prep*

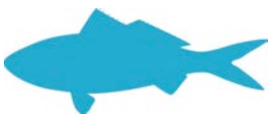
Prey first recovery: moderate and noisy



Predator

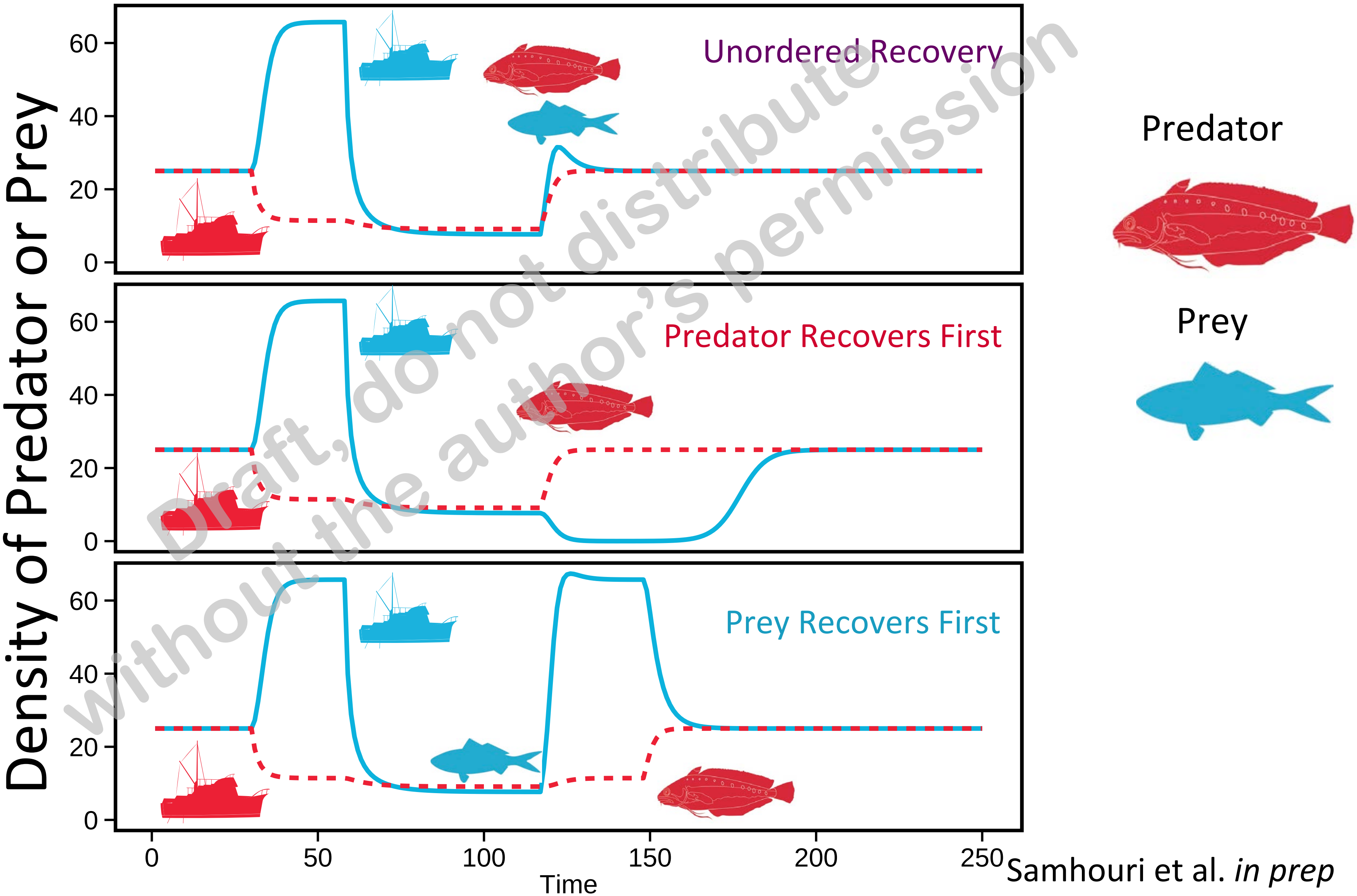


Prey



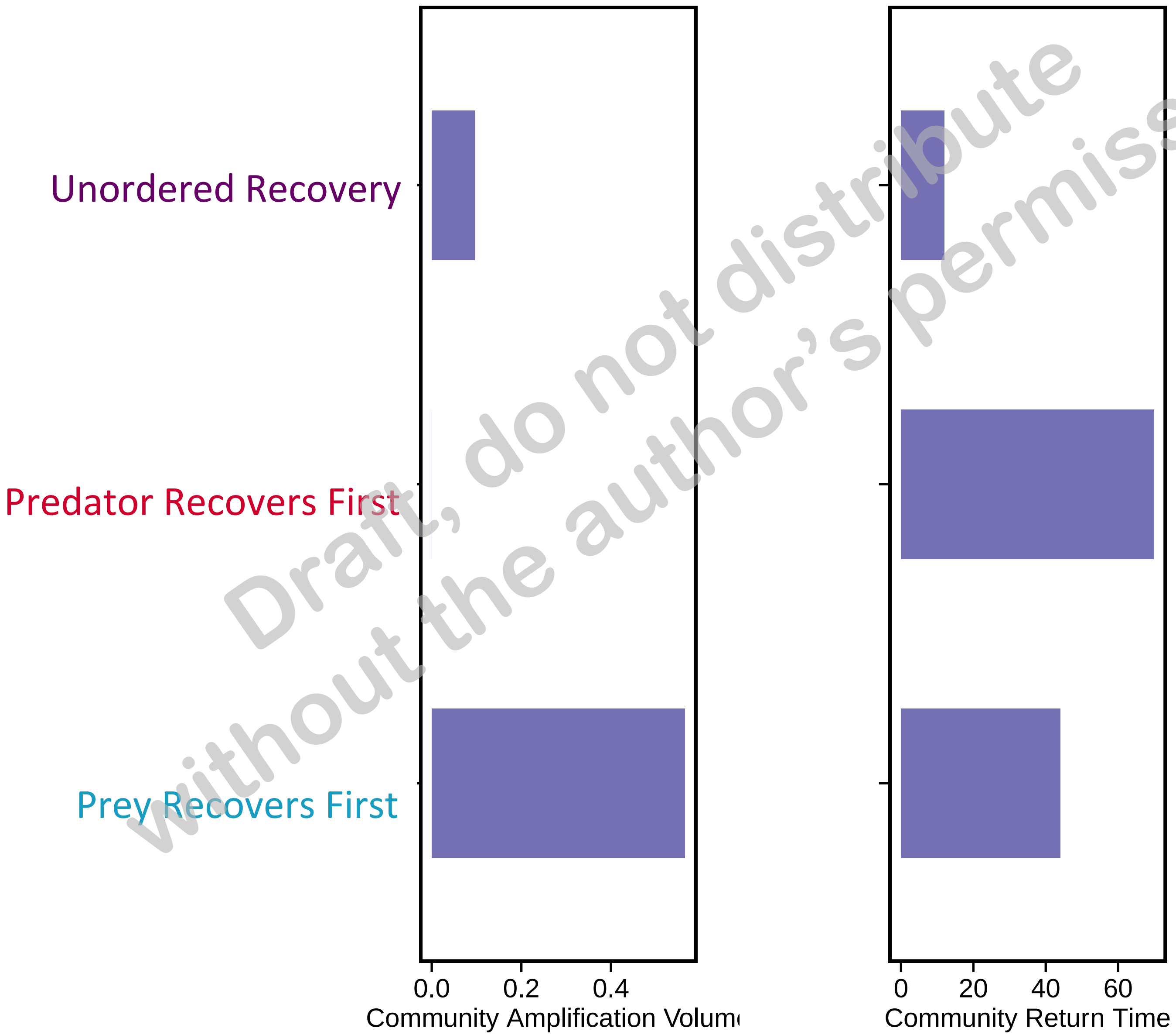
Samhouri et al. *in prep*

Trophic sequence of recovery matters



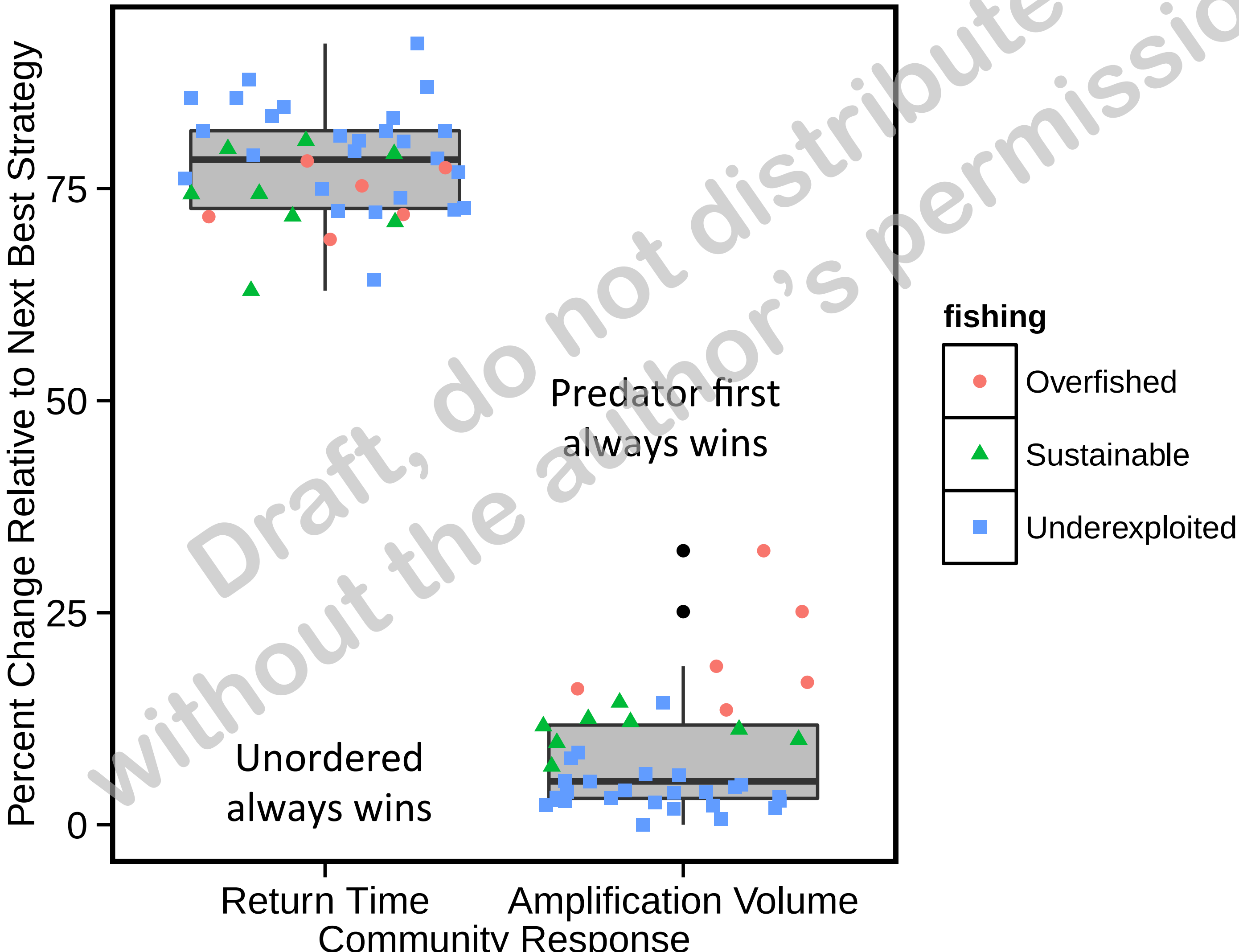
Samhouri et al. *in prep*

Trophic sequence of recovery matters



Samhouri et al. *in prep*

Strategic recovery is robust to differences in productivity regimes and exploitation scenarios



Early warning indicators of recovery?

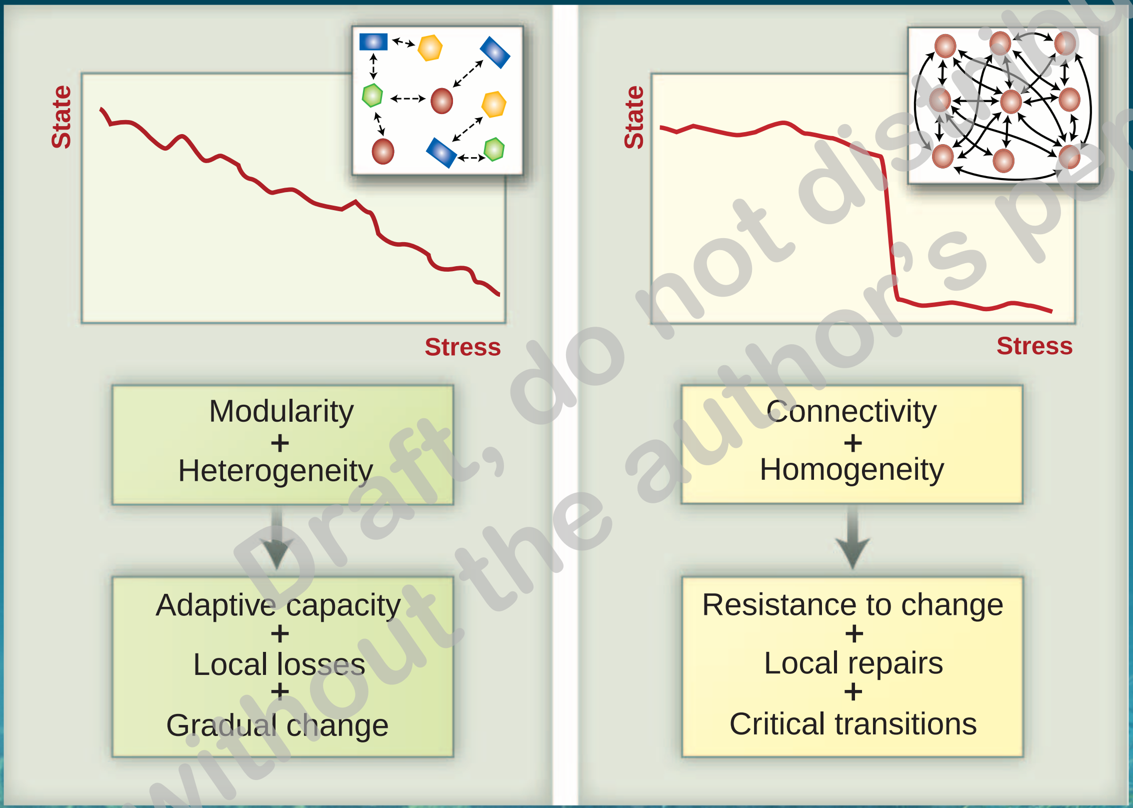
Samhouri et al. *in prep*

Management and conservation in a predictably surprising ocean

3 vignettes

1. The value of information in a world with tipping points
2. Robust management in a stochastic, threshold-constrained world
3. Strategic recovery once tipping points are crossed

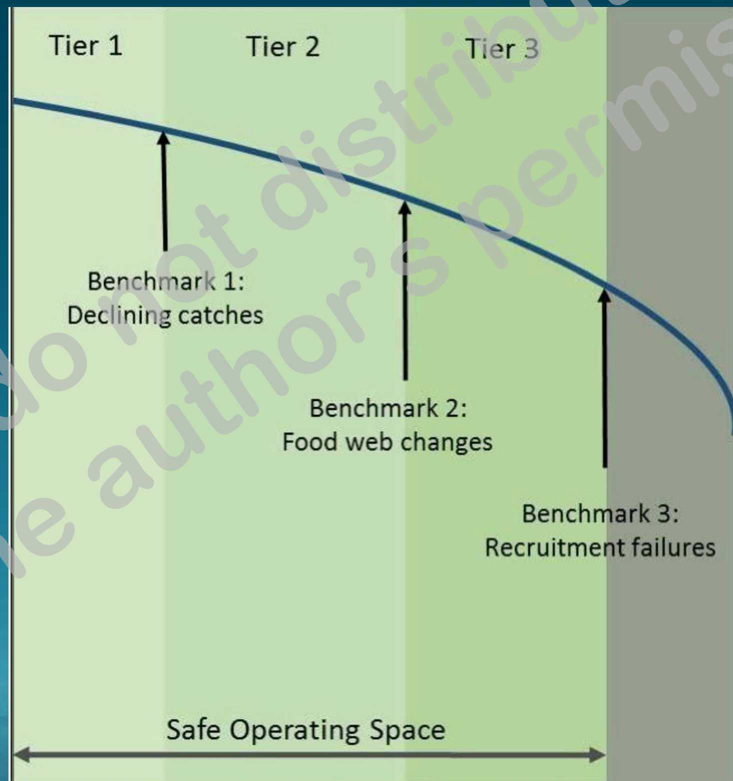
Predictable surprises require adaptive and robust management



Scheffer et al. 2012

Also see Levin 2001
"Immune systems
as ecosystems"

Fisheries and beyond: a hierarchy of tipping points



Tier	Risk of Tipping Point	Threat reduction	Monitoring Intensity
1	Low	None	Low
2	Moderate	Light	Moderate
3	High	Aggressive	High

Selkoe et al. in press

Take-home messages

1. Tipping points are common, but will be difficult to predict.

2. Develop a variety of biological models, including those that are mechanistic, spatial, and inherently nonlinear.

3. Design ecosystem-based management approaches robust to a range of potential futures.

SUSTAINABILITY

Prediction, precaution, and policy under global change

Emphasize robustness, monitoring, and flexibility

Schindler and Hilborn 2015

jameal.samhouri@noaa.gov

OCEAN TIPPING POINTS

Parting shots

- Model ensembles that include models with:
  - Mechanisms
  - Hysteresis
  - Spatial dynamics
- Evaluate management approaches that are robust to a range of potential futures
  - Insurance in the form of heterogeneity
  - Considerations beyond fisheries
- Use predictable social tipping points where ecosystem tipping points are unpredictable

jameal.samhouri@noaa.gov

Conclusion

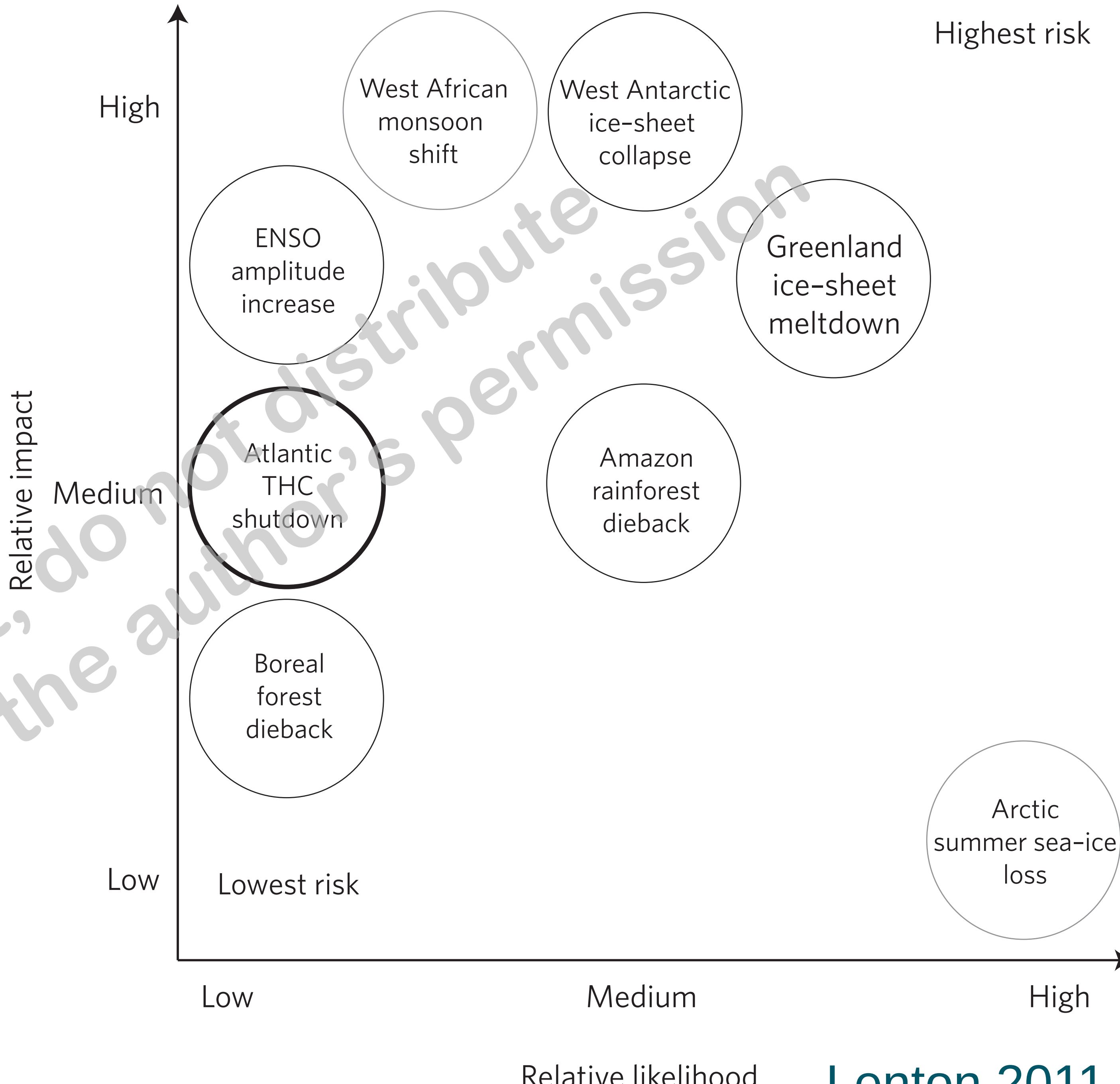
- Assuming linear change sets us up for surprises
- New approaches and tools can help integrate tipping points into marine management
- Doing so will yield better ecological outcomes and help sustain ecosystem benefits for the long run
- But we need more real world tests of these ideas – we still have a lot to learn!

Summary of principles for managing ecosystems prone to tipping points

Social-ecological observation	Management Principle
1. Tipping points are common.	*In the absence of evidence to the contrary, assume non-linearity.*
2. Intense human use may cause a tipping point by radically altering ecological structure and function.	*Address stressor intensity and interactive, cross-scale effects of human use to avoid tipping points.*
3. Early warning indicators of tipping points enable proactive responses.	*Work towards identifying and monitoring leading indicators of tipping points.*
4. Crossing a tipping point may redistribute ecosystem benefits.	*Work to make transparent the effects of tipping points on benefits, burdens and preferences.*
5. Tipping points change the balance between costs of action and inaction.	*Tipping points warrant increased precaution.*
6. Thresholds can guide target-setting for management.	*Tie management targets to ecosystem thresholds.*
7. Tiered management can reduce monitoring costs while managing risk.	*Increase monitoring and intervention as risk of a tipping point increases.*

Selkoe et al. *In Press*


OCEAN TIPPING POINTS


Highest risk
High
Medium
Low
Relative impact
West African monsoon shift
West Antarctic ice-sheet collapse
ENSO amplitude increase
Greenland ice-sheet meltdown
Atlantic THC shutdown
Amazon rainforest dieback
Boreal forest dieback
Arctic summer sea-ice loss
Lowest risk
Low
Medium
High
Relative likelihood

Lenton 2011

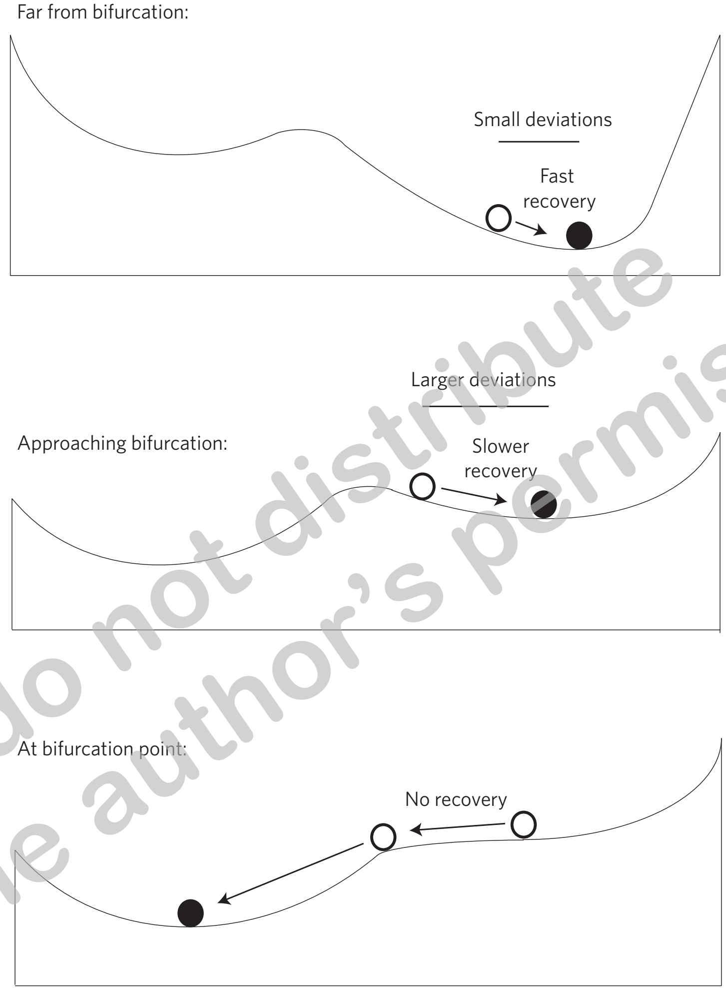
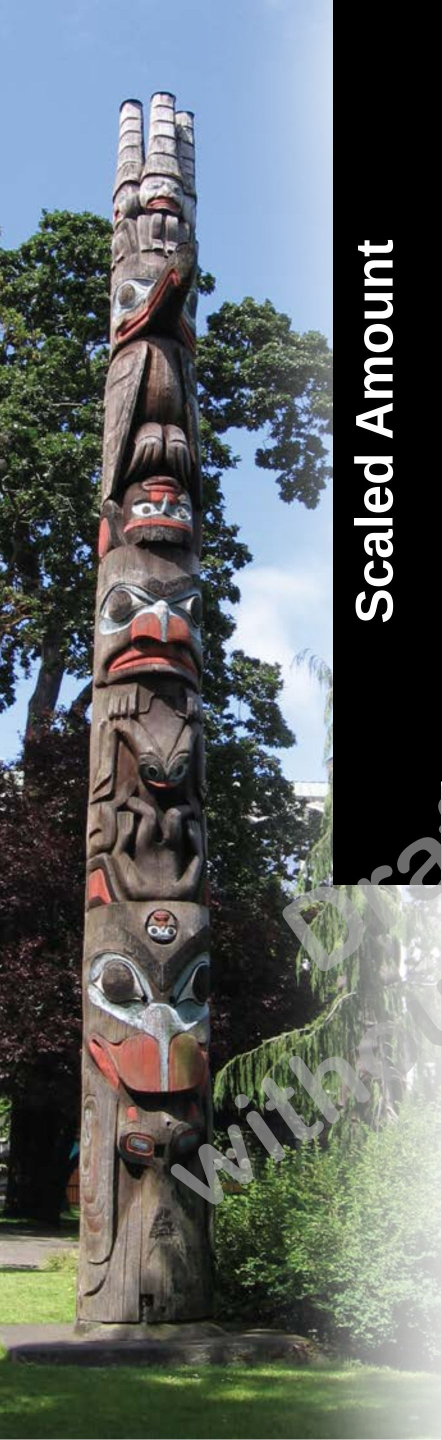
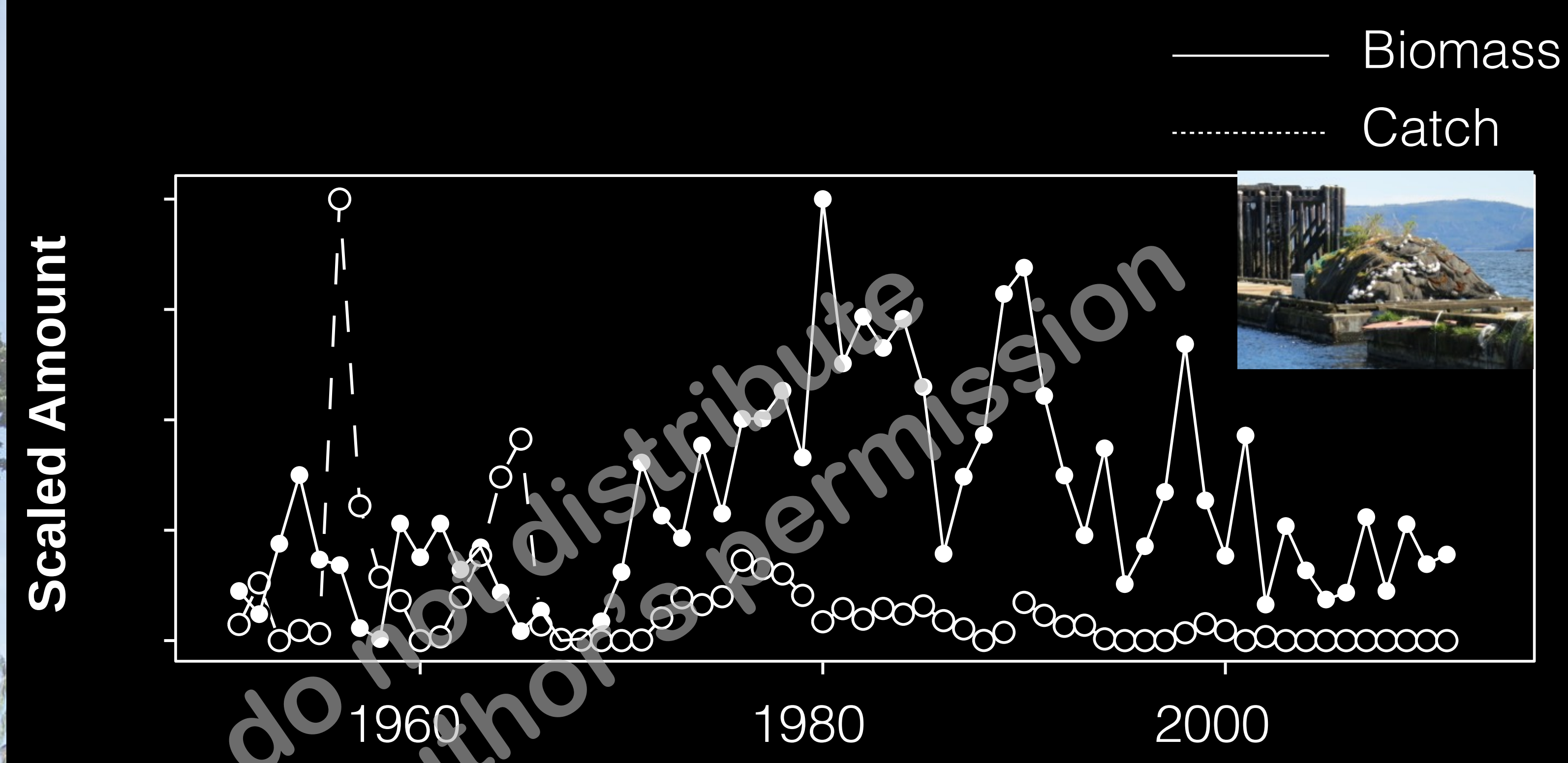


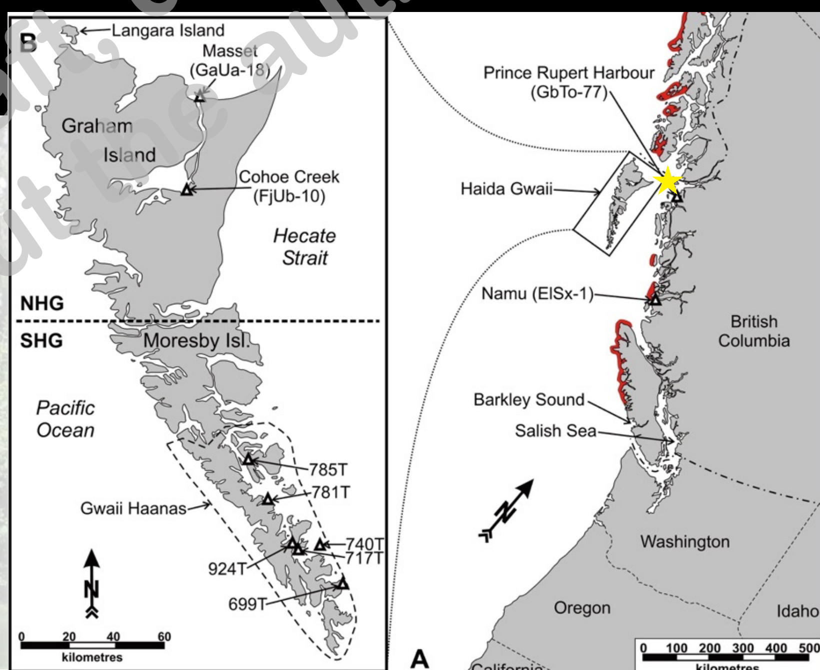
Figure 2 | Heuristic basis for early warning of an approaching bifurcation point. The valleys or potential wells represent stable attractors and the ball represents the state of the system. Under gradual forcing, the right potential well becomes shallower and finally vanishes (bifurcation) causing the ball to role abruptly to the left. Picture the system being nudged around by a short-term stochastic process (noise). The radius of the potential well is directly related to the system's response time to such small perturbations, which tends towards infinity as bifurcation is approached, that is, the system becomes more sluggish in response to perturbations ('critical slowing down'). Larger fluctuations are also expected as bifurcation is approached.

Lenton 2011





Biomass
Catch
Scaled Amount
1960
1980
2000



B
Langara Island
Masset (GaUa-18)
Graham Island
Cohoe Creek (FjUb-10)
Hecate Strait
NHG
SHG
Moresby Isl.
Pacific Ocean
785T
781T
Gwaii Haanas
740T
717T
924T
699T
0 20 40 60
kilometres
Prince Rupert Harbour (GbTo-77)
Haida Gwaii
Namu (ElSx-1)
British Columbia
Barkley Sound
Salish Sea
Washington
Oregon
Idaho
A
0 100 200 300 400 500

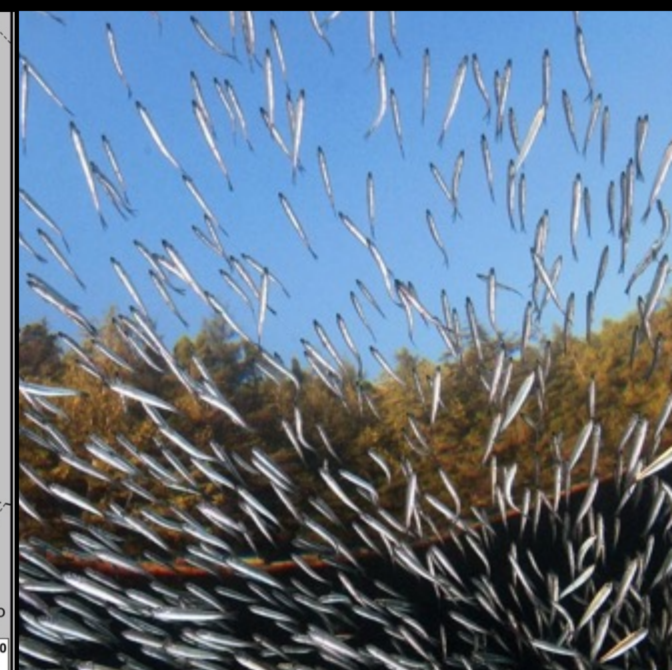


Table 1 | Early warning indicators of approaching bifurcation points and tests thereof.

Phenomenon	Indicator	System	Data Source	Signal	Reference(s)
Critical slowing down	Increasing autocorrelation, AR(1) coefficient	Climate	Models	+	8, 10, 12, 53
			Palaeorecord	+	10, 12, 53
				0	12, 13
		Ecological	Models	+	44
	Increasing return time from perturbations	Ecological	Models	+	39, 40, 45, 51
			Lab experiments	+	6, 52
	Increasing DFA exponent	Climate	Models	+	9, 11, 12
			Palaeorecord	+	9, 12
				–	12
	Spectral reddening	Climate	Models	+	7
		Ecological	Model	0	79
	Increasing spatial correlation	Ecological	Models	+	47
			Lab experiments	+	52
Increased variability	Increasing variance	Climate	Models	+	12
				0	12
			Palaeorecord	+	12
				0	13
				–	12
		Ecological	Models	+	43–45, 79
			Lab experiments	+	52
	Increasing spatial variance	Ecological	Model	+	48
			Data	+	49
			Lab experiments	+	52
Skewed responses	Increasing skewness	Climate	Palaeodata	0	46
		Ecological	Model	+	44–46
			Lab experiments	+	52
	Increasing spatial skewness	Ecological	Model	+	48

'+' means indicator increased as expected; '–' means indicator decreased, contrary to expectation; '0' means there was no significant change in the indicator.

Lenton 2011


OCEAN TIPPING POINTS
www.oceantippingpoints.org
OUR PARTNERS
UCSB
NCEAS
NOAA
CENTER FOR OCEAN SOLUTIONS
EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work
GORDON AND BETTY MOORE FOUNDATION