DEVELOPMENT OF ECOSYSTEM INDICATORS TO CHARACTERIZE ECOSYSTEM RESPONSES TO MULTIPLE STRESSORS: A SUMMARY OF PICES WORKING GROUP 28

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PICES Working Group 28 Terms of Reference (shortened)

(7 Terms of Reference in total)

- Identify critical stressors in North Pacific marine ecosystems
- Identify categories of indicators to identify ecosystem change at a variety of spatial scales
- Review frameworks linking stressors to impacts, and their applicability to North Pacific ecosystems
- For 1-2 case studies, identify how these ecosystems respond to multiple stressors using these proposed indicators

PICES Working Group 28 Participants

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Co-chairs: Motomitsu Takahashi, Ian Perry

Concept of single *vs.* multiple stressors

Sector activity

generates

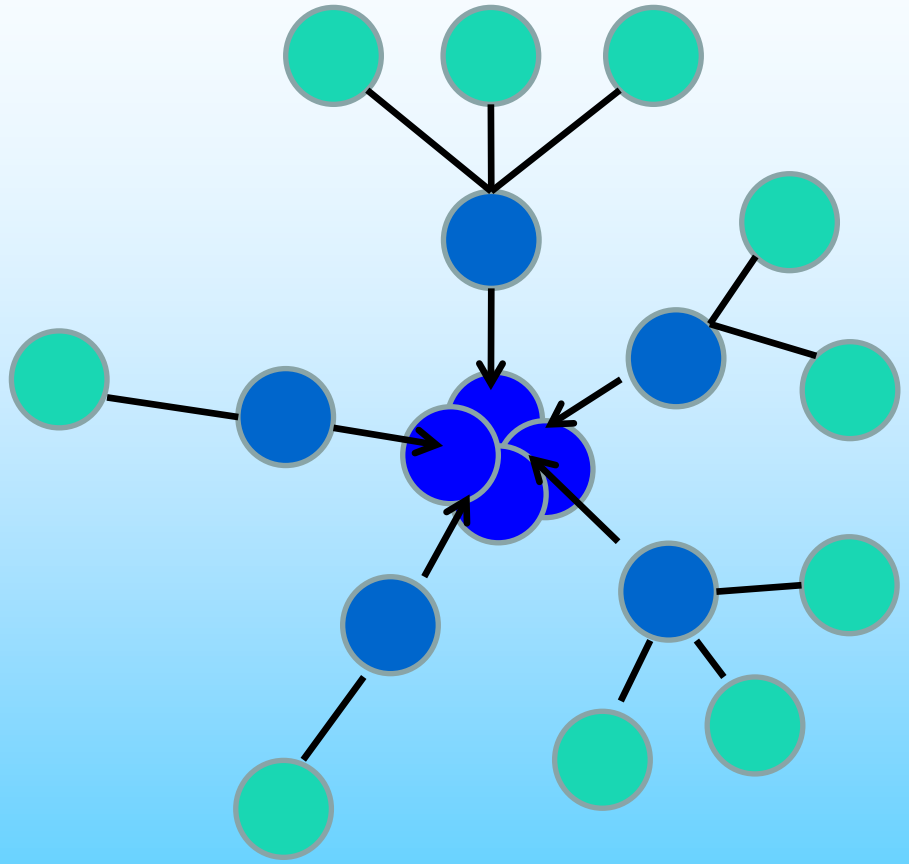
Pressure

that impacts

Ecological characteristic

Knights et al. 2013.

Impact Chain



Multiple Sector Impacts

Report outline

Development of Ecosystem Indicators to Characterize Ecosystem Responses to Multiple Pressures (PICES Scientific Report, In Prep'n)

Chapter 1: "Introduction"

Chapter 2: "Frameworks linking pressures to impacts and changes in North Pacific marine ecosystems"

Chapter 3: "Multiple pressures on North Pacific marine ecosystems"

Chapter 4: "Case Studies"

Chapter 5: "Developing ecosystem indicators for responses to multiple pressures"

Chapter 6: "Ecosystem indicators for ecosystem responses to multiple pressures in the North Pacific"

Chapter 7: "Summary and Conclusions"

Presentation outline

WG 28 was not able to propose one comprehensive ecosystem indicator for the North Pacific

Instead:

- Reviewed ecosystem indicators proposed for elsewhere, for their applicability to the North Pacific
- Reviewed frameworks and methods to select indicators appropriate for North Pacific waters
- Identified common pressures on North Pacific marine ecosystems

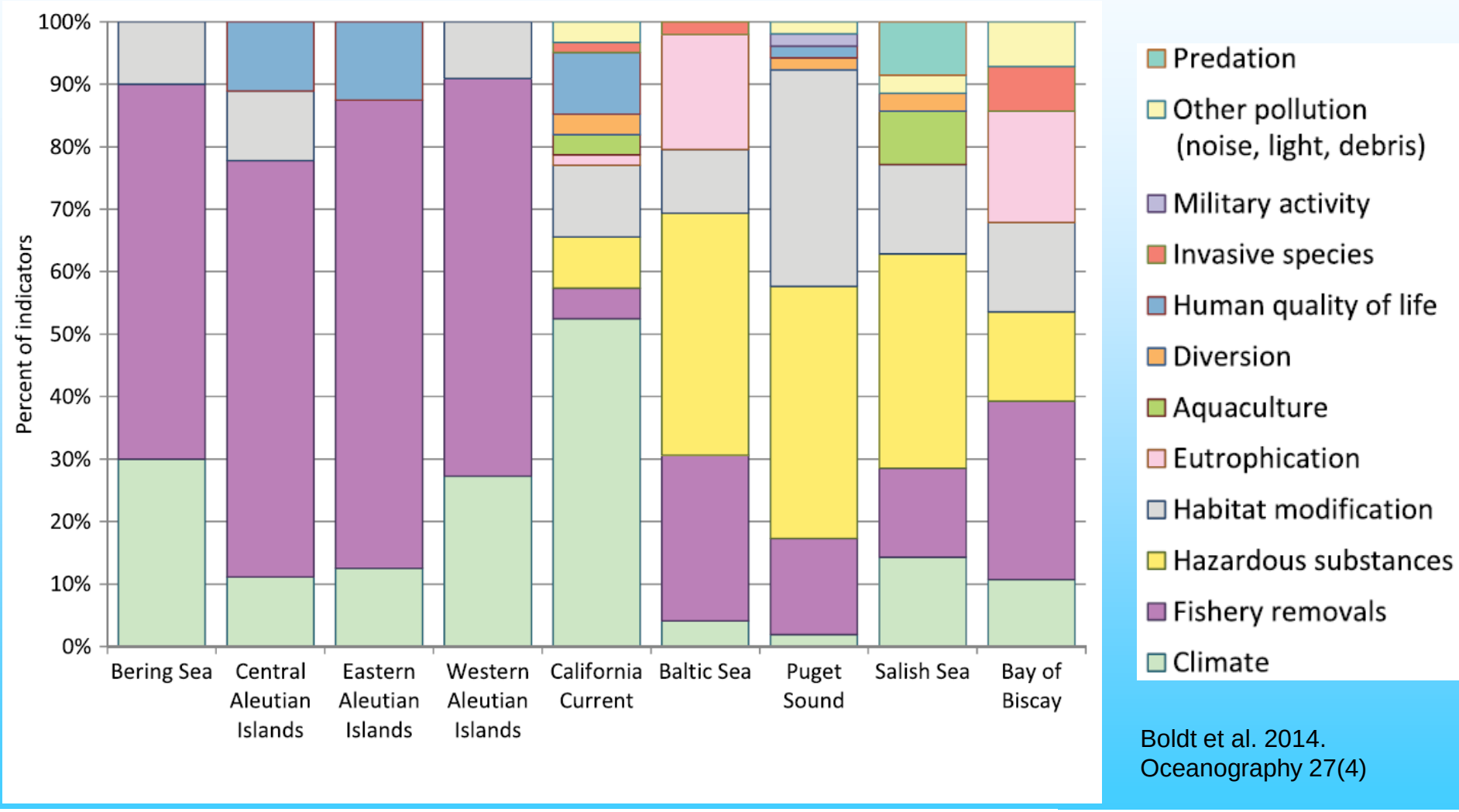
Conclude with thoughts for WG 36

Indicators: Integrated "core set"

Type	Indicator
Climate	ENSO(MEI), PDO, NPGO,
Physical environment	SST, Sea ice area, Freshwater discharge
Chemical environment	Nitrate, pH, O_2
Contaminants	PCB, POP, Mercury
Fishing / aquaculture	Total landings, Trophic level of landings, Taxonomic diversity of landings, Landings of selected species

Type	Indicator
Biological environment	Chl*a*, HABs, Crustacean plankton biomass, Gelatinous plankton biomass, Small pelagic fish biomass, Demersal fish biomass, Piscivorous fish biomass, Top predator biomass, SSB (selected species), Slope of size spectrum, Species richness, Taxonomic diversity, Number of taxa representing 80% of biomass

Indicators: Comparison across ecosystems



Boldt et al. 2014. Oceanography 27(4)

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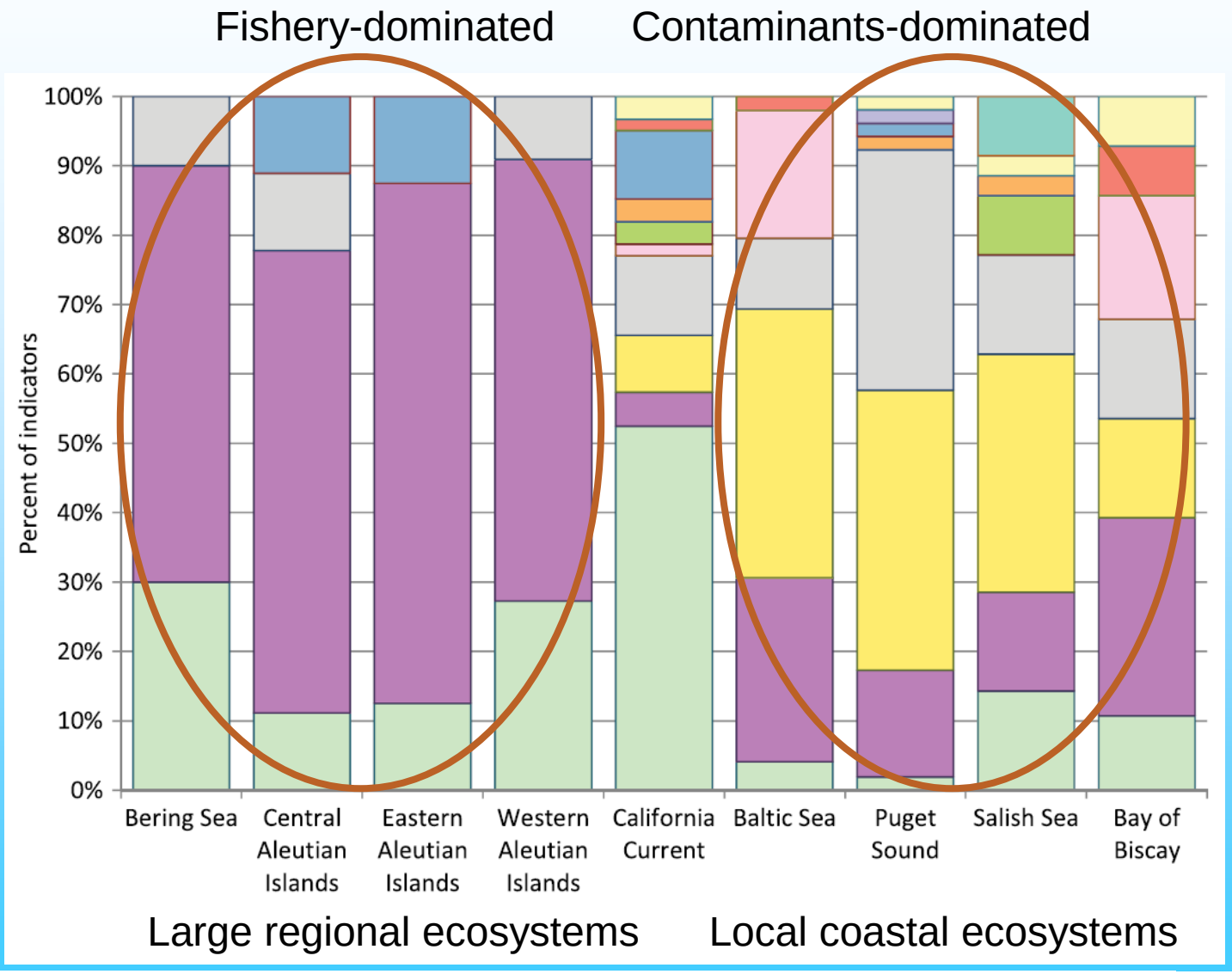


Boldt et al. 2014. Oceanography 27(4)

Comparison of programs identifying suites of indicators

Similarities:

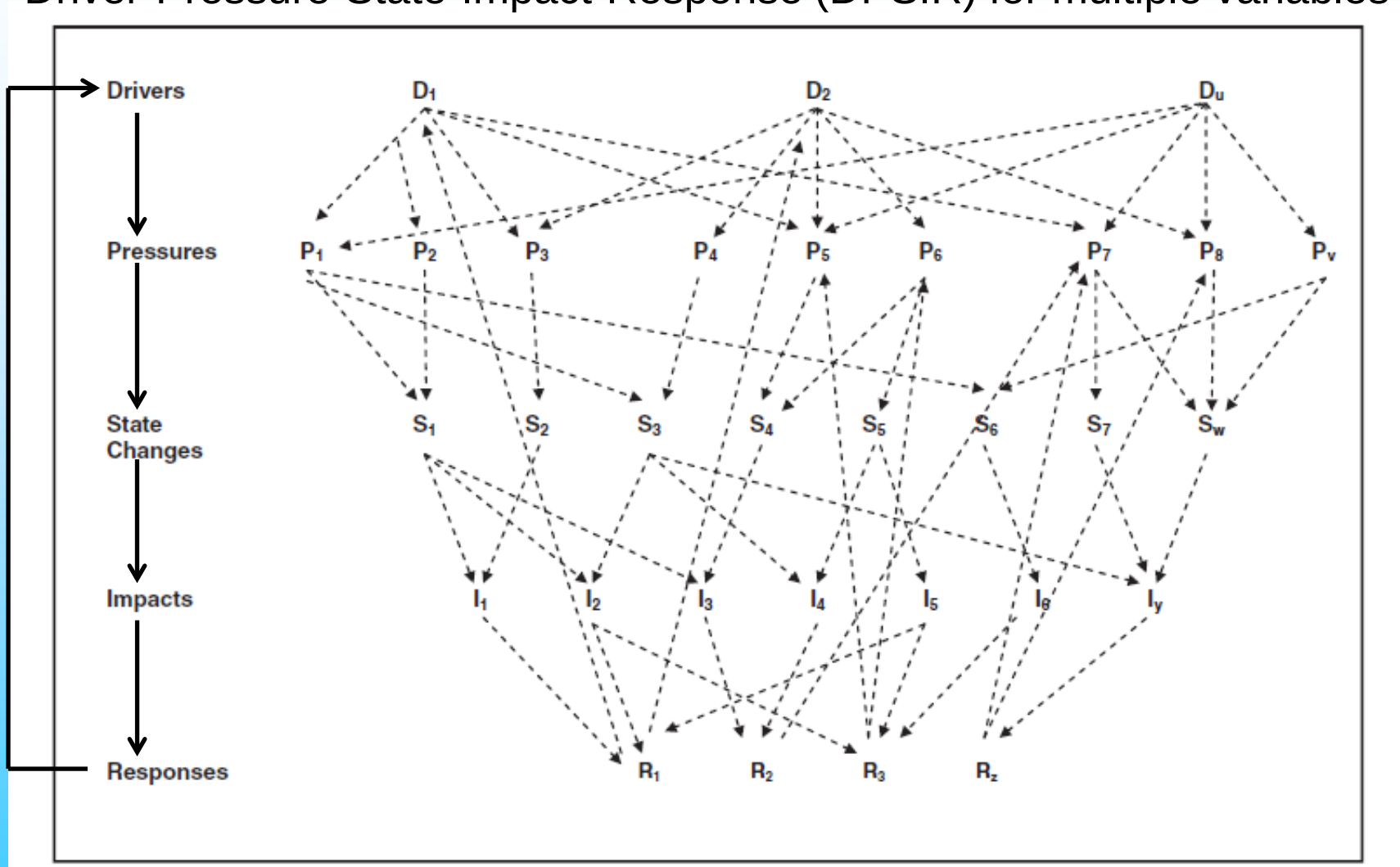
- potential indicators were identified and refined by data availability, selection criteria and, in some cases, expert knowledge.
- key functional groups with fast and slow dynamics and essential ecosystem characteristics were represented.
- considered the effect of multiple stressors on ecosystems in tables or text

Differences:

- overall objective of assessment: state, progress towards targets, ecosystem-based fishery management goals, marine management goals
- main pressures acting on ecosystems and the spatial delineation of the ecosystems
- species composition and key functional groups/features
- the level of detail thought appropriate for communicating to a public, non-scientific audience
- the experts involved
- data availability

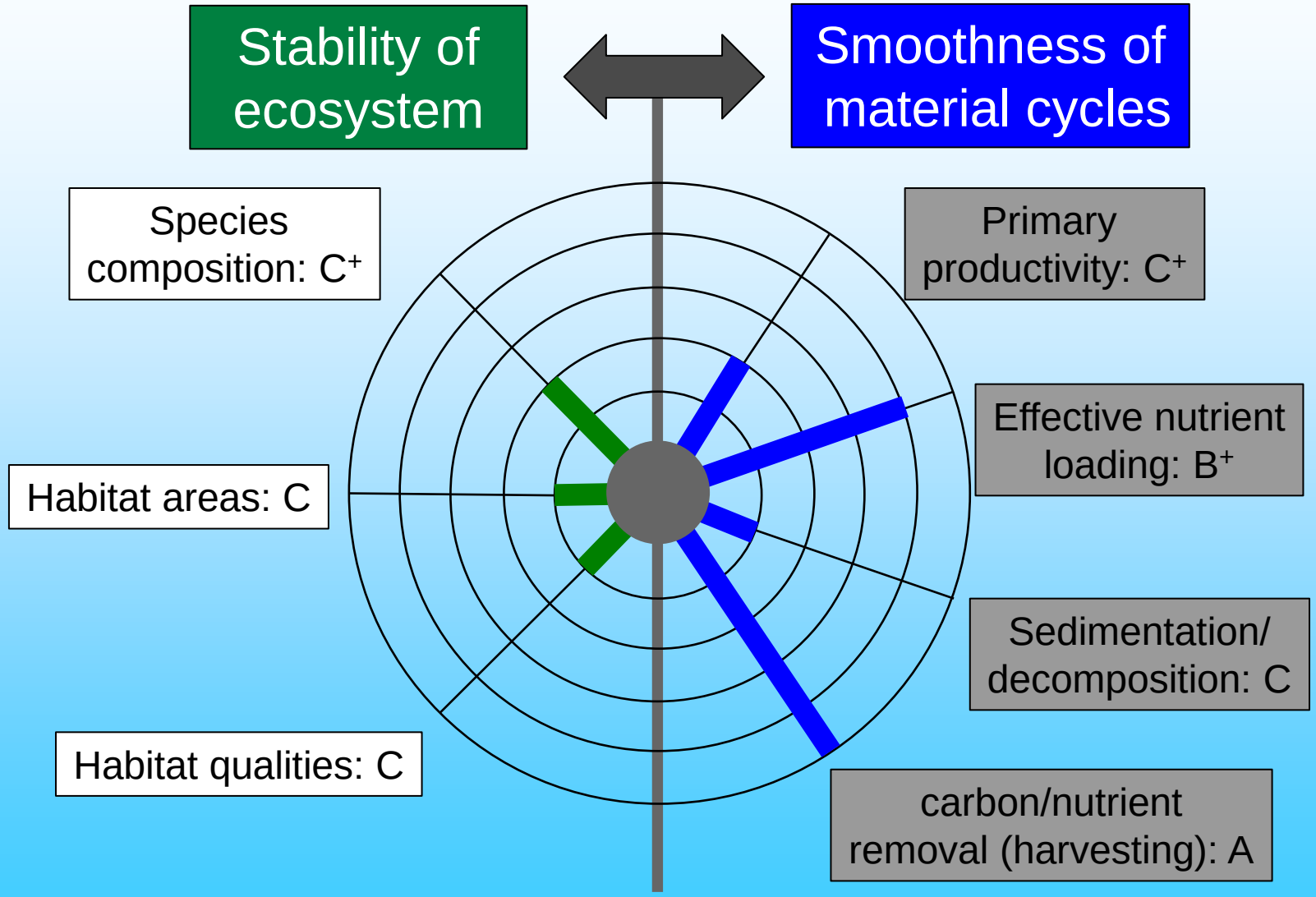
Frameworks for selection of marine ecosystem indicators

Driver-Pressure-State-Impact-Response (DPSIR) for multiple variables



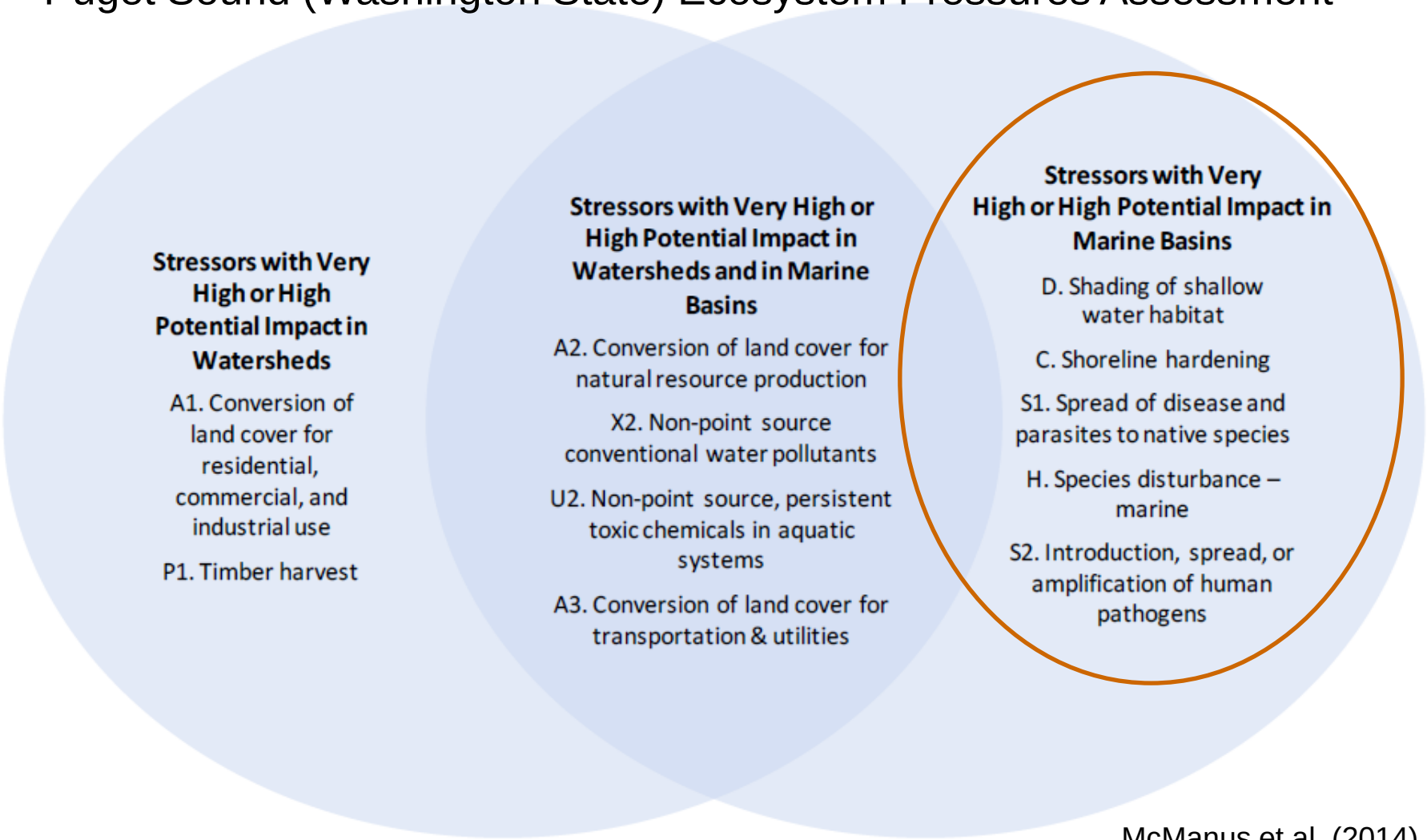
Frameworks for selection of marine ecosystem indicators

Ecosystem “health chart” for Ise Bay (Mie/Aichi Prefectures, Japan)



Multiple pressures in the North Pacific – Local spatial scales

Puget Sound (Washington State) Ecosystem Pressures Assessment



McManus et al. (2014)

Multiple pressures in the North Pacific – Regional spatial scales

Land-based	Nutrients (fertilizer) Organic pollutants (pesticides) Inorganic pollutants (impervious surfaces) Direct human (population density)
Ocean-based	Oil rigs Invasive species Ocean pollution Shipping
Fishing	Artisanal fishing Pelagic, low-bycatch fishing Pelagic, high-bycatch fishing Demersal, destructive fishing Demersal, non-destructive, low-bycatch fishing Demersal, non-destructive, high-bycatch fishing
Climate	SST UV Ocean acidification

Halpern et al. 2008 Science

Multiple pressures in the North Pacific (literature + case studies)

Activities/Stressors
1. Pollution from land
2. Coastal engineering
3. Coastal development
4. Direct human impact
5. Ecotourism
6. Commercial activity
7. Aquaculture
8. Fishing - demersal
9. Fishing - pelagic
10. Fishing - illegal
11. Offshore development
12. Pollution from ocean
13. Freshwater input
14. Sediment input
15. Nutrient input
16. HABs
17. Hypoxia
18. Species invasion
19. Sea level change
20. Sea temperature

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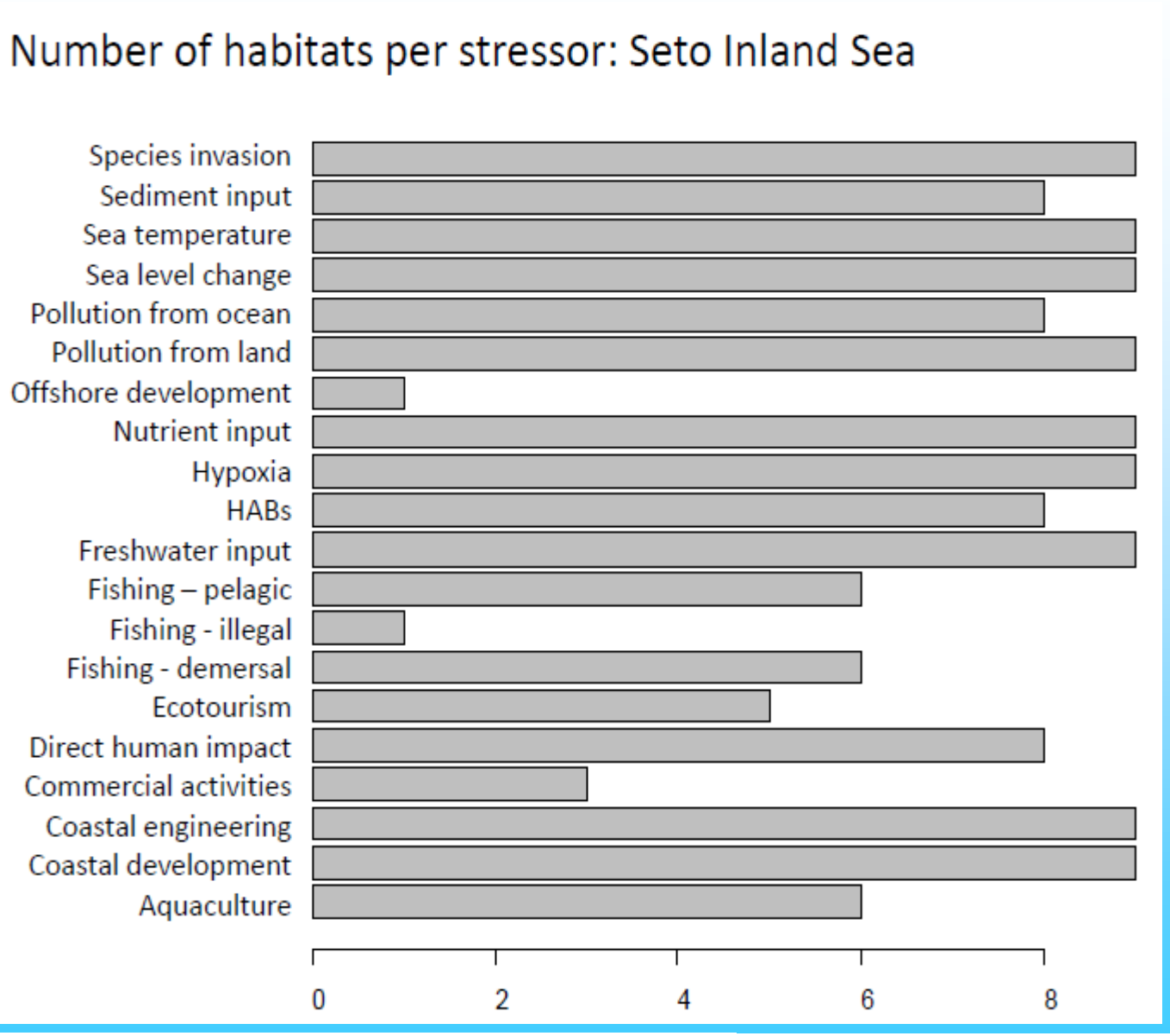

Main pressures impacting ecosystems in East China Sea, Seto Inland Sea, Kuroshio/Oyashio

Activities/Stressors	ECS/YS	SETO	K/O
1. Pollution from land	2.7	3.0	
2. Coastal engineering	3.4	3.2	
3. Coastal development	3.4	3.2	
4. Direct human impact		3.0	
5. Ecotourism		2.3	
6. Commercial activity		3.0	
7. Aquaculture		3.0	
8. Fishing - demersal	3.5	2.9	2.8
9. Fishing - pelagic	2.6	2.7	3.3
10. Fishing - illegal		2.6	
11. Offshore development	2.1	2.9	
12. Pollution from ocean	3.1	2.9	
13. Freshwater input	2.9	2.7	
14. Sediment input	2.5	2.8	
15. Nutrient input	2.9	3.1	3.0
16. HABs	2.8	2.7	
17. Hypoxia	3.2	2.8	3.0
18. Species invasion	2.5	2.9	
19. Sea level change		3.1	3.2
20. Sea temperature	3.2	3.5	3.2

Coastal development and engineering have strong impacts to the ECS/YS and the Seto Inland Sea.

Demersal and pelagic fishing impact the ECS/YS and the K/O, respectively.

Nutrient input has resulted in HABs and Hypoxia in summer.

Increasing sea temperature strongly affects all 3 ecosystems.

Ecosystem indicators for multiple pressures in the North Pacific

- Single indicators are generally inadequate
  - Use a “core set” supplemented with issue-specific indicators
- Indicators likely to differ between regional coastal systems, and deep ocean

- Therefore: need a process to identify ecosystem indicators for multiple pressures in the North Pacific

Measured variables

Distributional range

Distributional pattern within the range

Population abundance and/or biomass

Population demographics

Spawning stock biomass

Ratio of planktivorous to piscivorous fish

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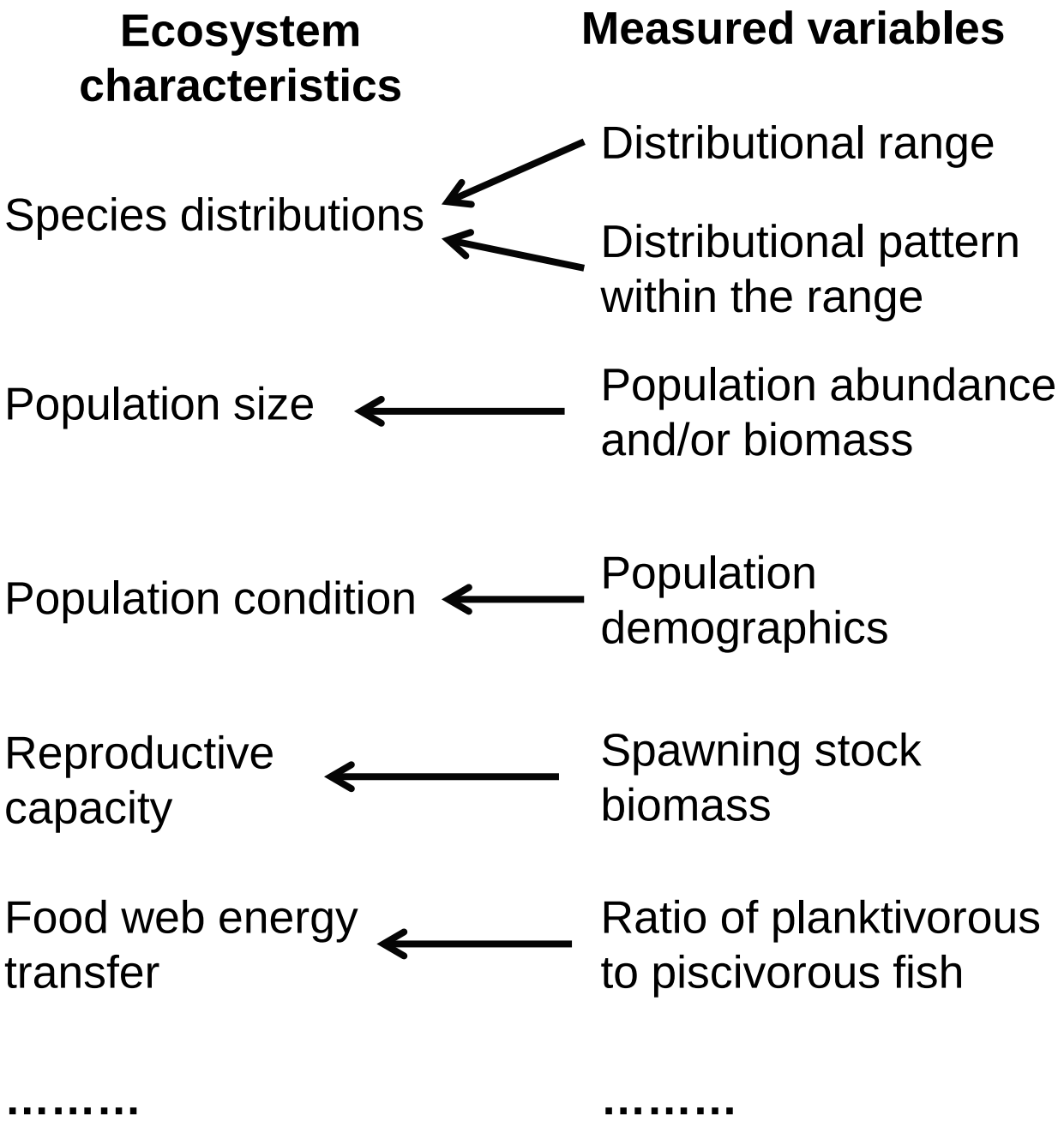
Ecosystem characteristics
Measured variables
Species distributions
Distributional range
Distributional pattern within the range
Population size
Population abundance and/or biomass
Population condition
Population demographics
Reproductive capacity
Spawning stock biomass
Food web energy transfer
Ratio of planktivorous to piscivorous fish
.....
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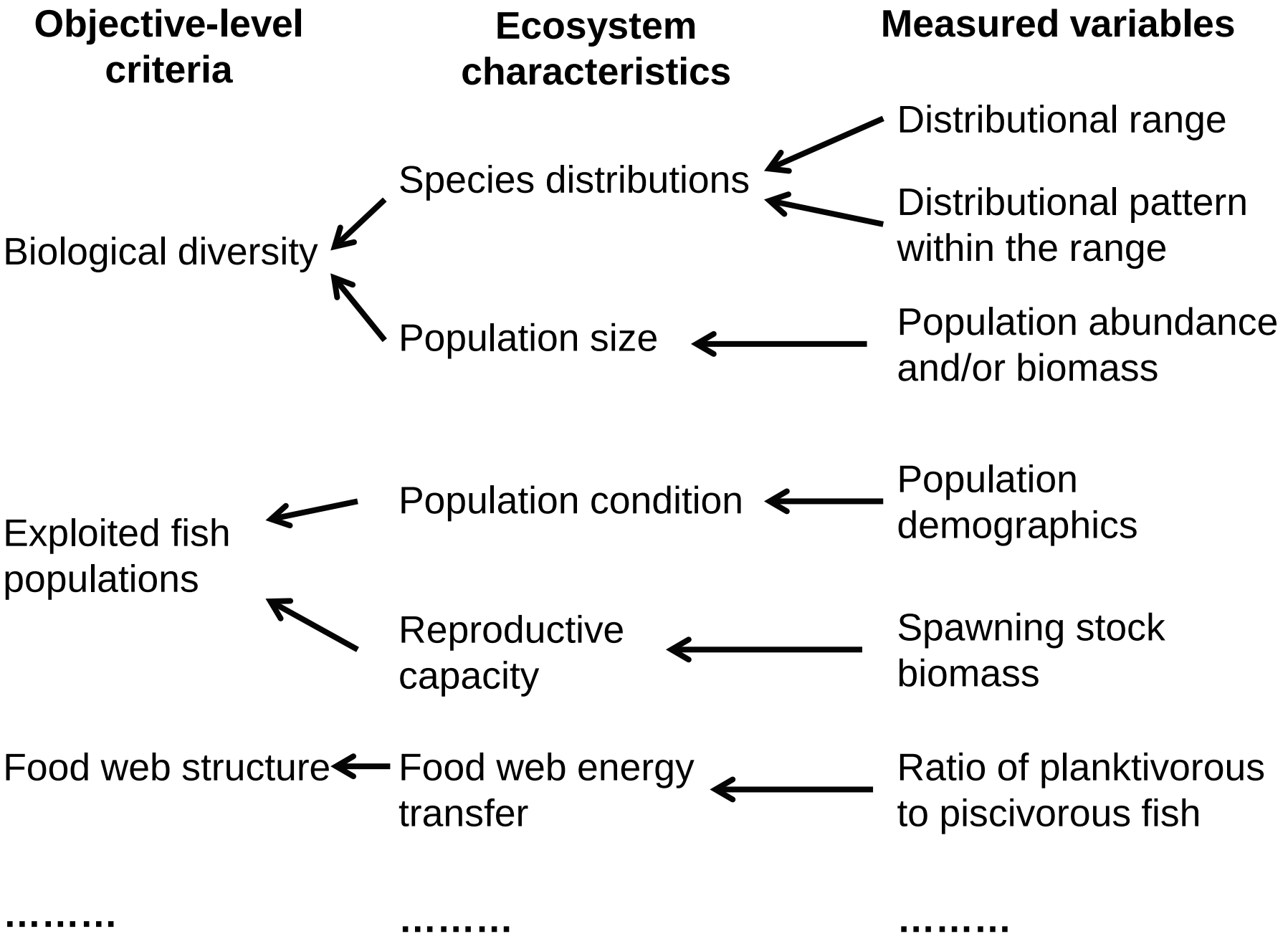
Objective-level criteria
Ecosystem characteristics
Measured variables
Distributional range
Species distributions
Distributional pattern within the range
Biological diversity
Population size
Population abundance and/or biomass
Population condition
Population demographics
Exploited fish populations
Reproductive capacity
Spawning stock biomass
Food web structure
Food web energy transfer
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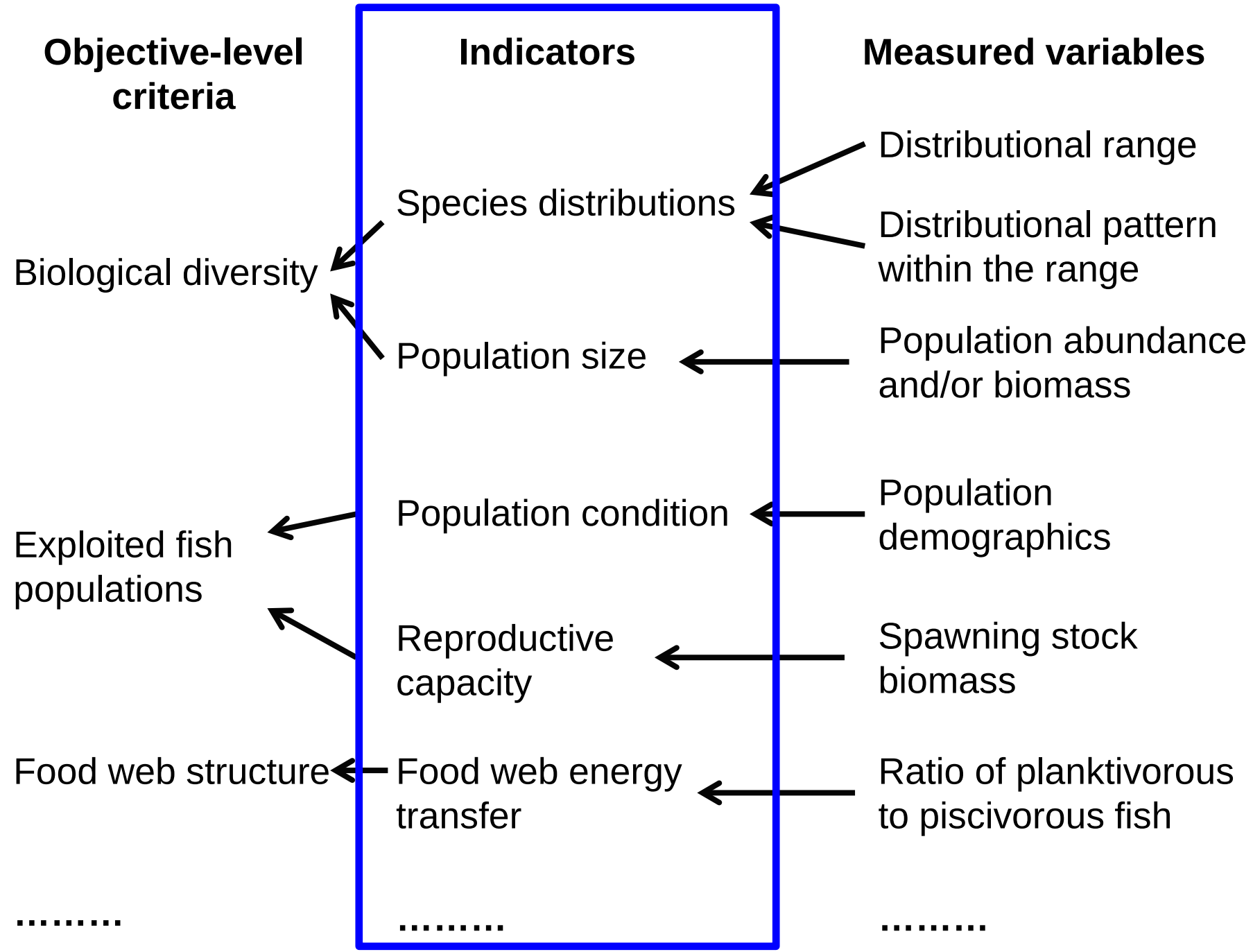
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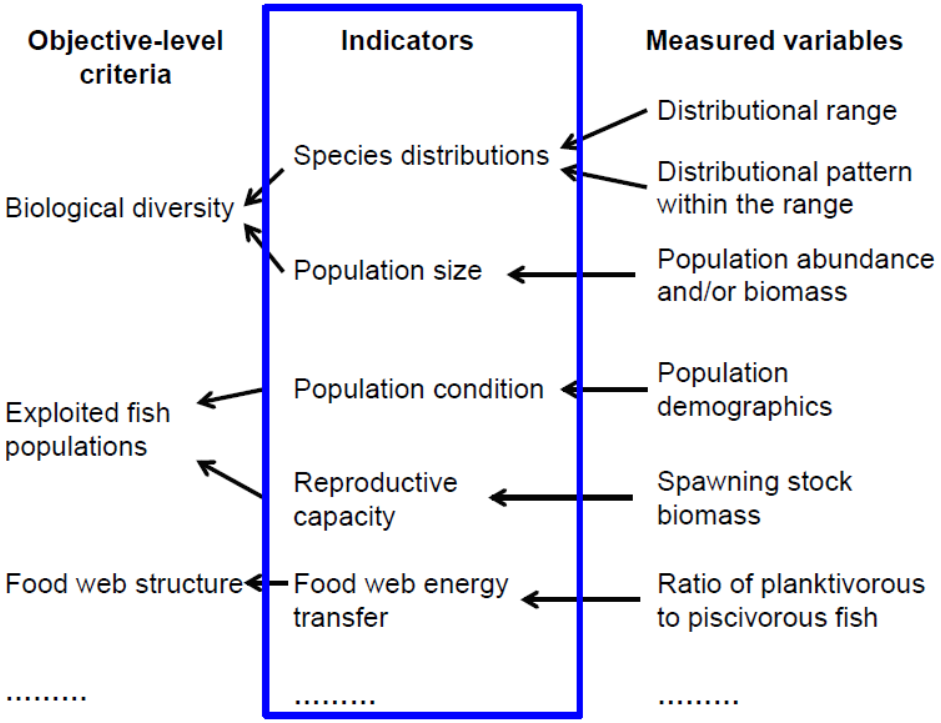

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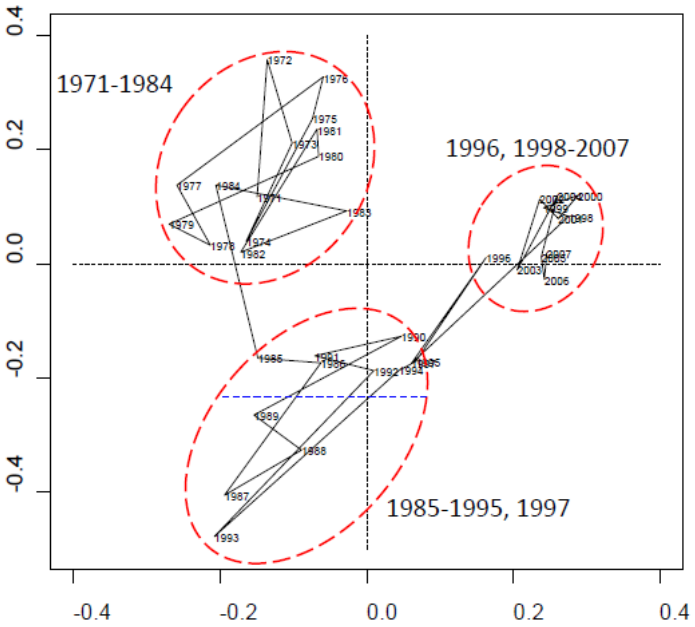
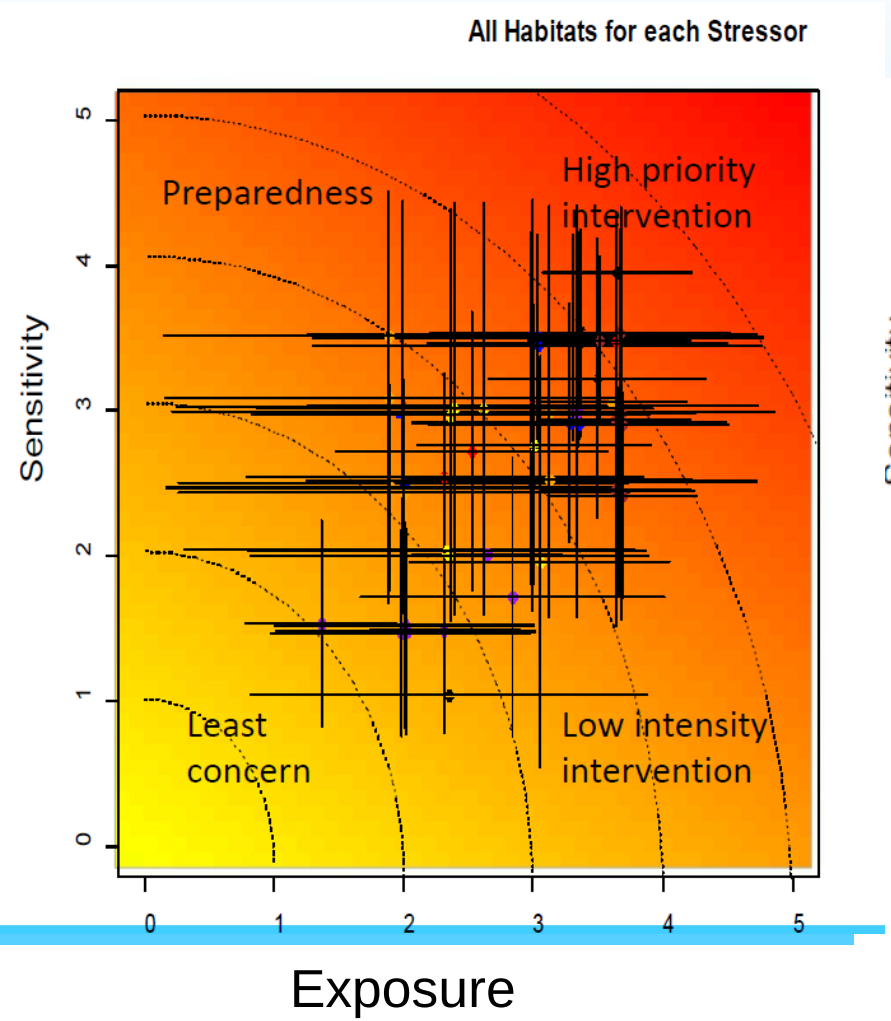


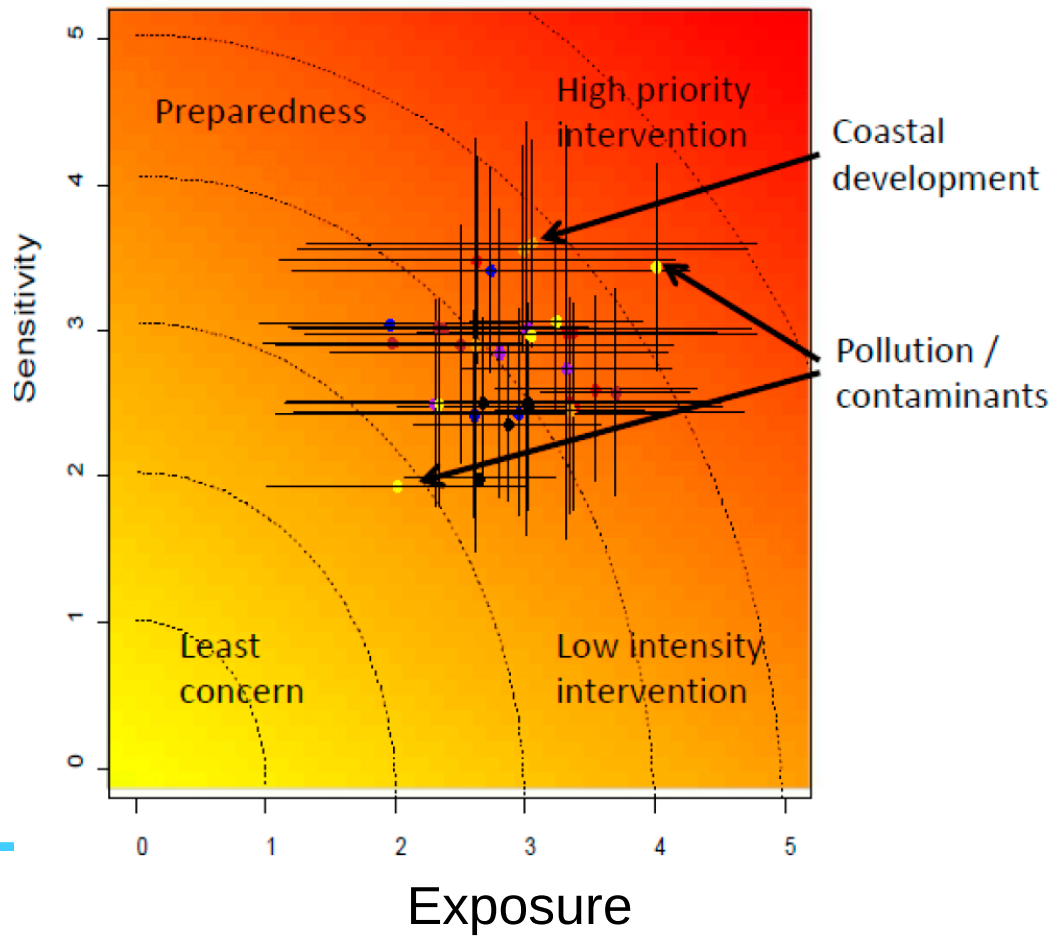
Example from Perry and Masson. 2013. Progr. in Oceanogr.

Multiple pressures and risk assessment in the North Pacific

Seto Inland Sea, Japan



Strait of Georgia, Canada



(Some of the) WG 28 Lessons Learned

- Multiple pressures are common; single pressures are rare
- There are more pressures, and greater impacts, in coastal than offshore systems
- However, there may be a shorter list of important pressures at regional scales. i.e., climate change impacts may overwhelm all other pressures
- Ecosystem responses to multiple pressures are non-uniform: a suite of indicators is best to capture a diversity of ecosystem responses.
  - There is no one integrating indicator for all ecosystems of the North Pacific
- Interactions between multiple pressures may be additive, synergistic, or antagonistic
- Climate and fishing provide examples of how interactions between pressures can act non-additively in some cases and additively in others to change the dynamics of exploited fish populations.

Thoughts for WG 36

Since there is no single integrating ecosystem indicator for the North Pacific, a suite of ecosystem indicators will be necessary

Toolbox approach:

- use a core set of indicators for all ecosystems (e.g. many listed in WG28 report);
- include additional ecosystem-specific, pressure-linked response indicators (not reflected in the core set) as necessary

Risk diagrams (exposure *vs* sensitivity) may be useful to assist with defining Reference Points