Representing nutrient dynamics in an ecosystem model of Puget Sound

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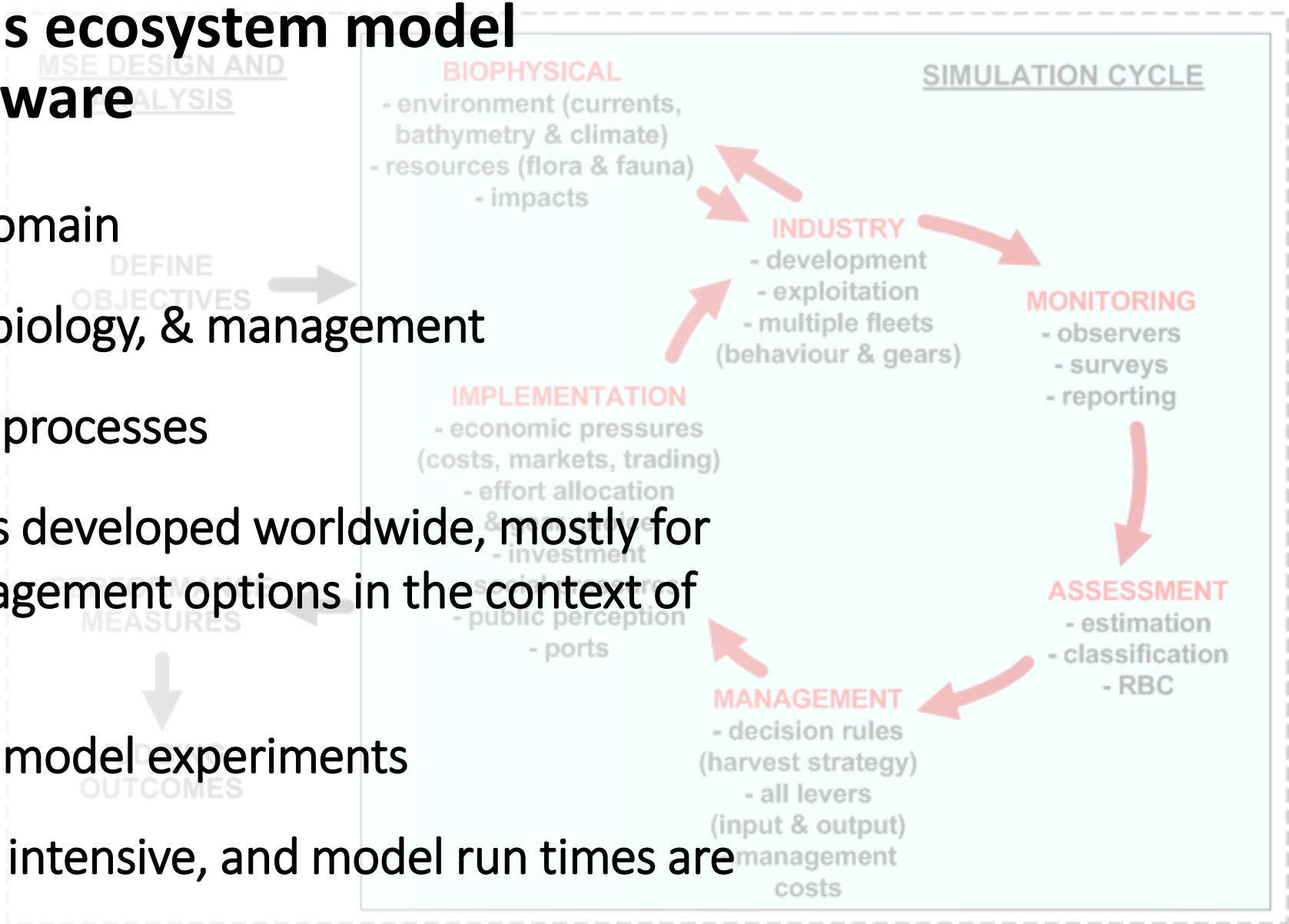
As part of the Salish Sea Marine Survival Project, we are building an ecosystem model to examine factors that are individually or cumulatively responsible for recent increases in salmon mortality

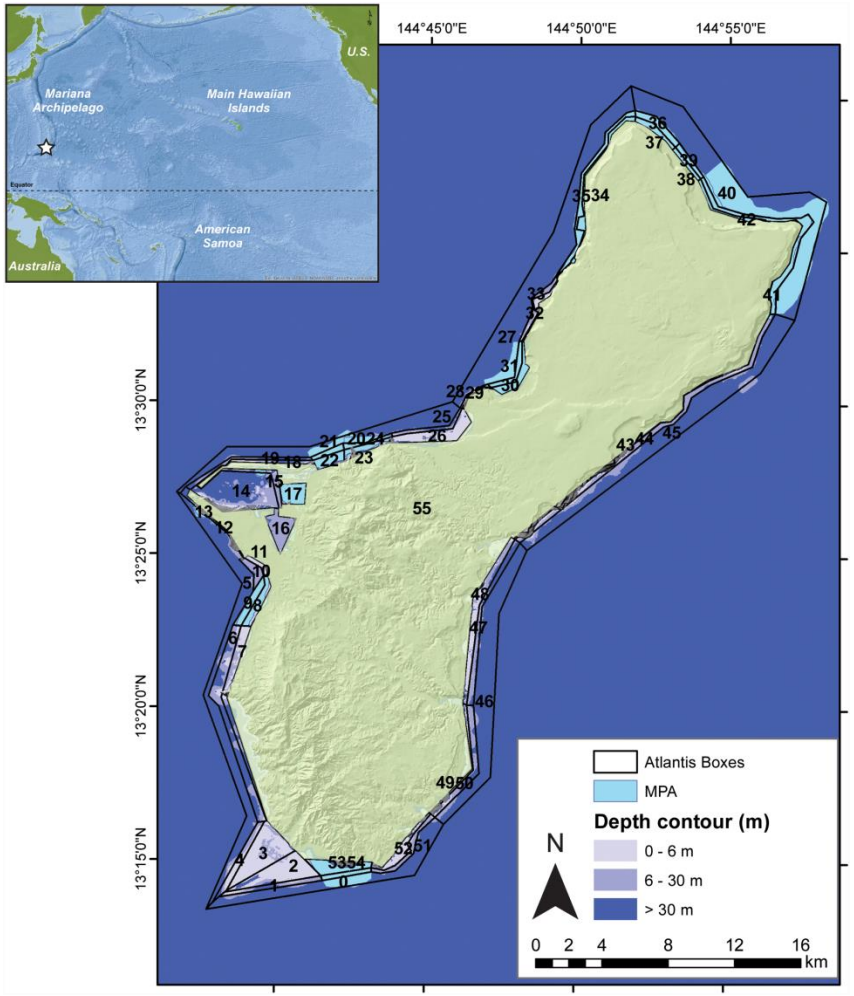
- Changes in bottom-up processes? (nutrients, productivity, climate)
- Changes in top-down processes? (predation)
- Changes in other food web processes? (competition)
- Changes in other drivers? (contaminants, fishing, habitat)
- Differences among basins?

We are developing this ecosystem model using the Atlantis software

- Spatially explicit model domain
- Links physics, chemistry, biology, & management
- Flexibility with ecological processes
- Dozens of Atlantis models developed worldwide, mostly for comparing fisheries management options in the context of environmental variability
- A “sandbox” for strategic model experiments
- Downside: complex, data intensive, and model run times are slllllllowwwwwwww…



Example: ecosystem services of corals around Guam



- 55 spatial polygons
- 42 functional groups, from bacteria up to sea turtles
- Key drivers of coral reef system dynamics:
  - Global change (↑ temperature, ↓ pH)
  - Nutrient/sediment loading
  - Fishing
- Scenarios:
  - IPCC high CO_2-emission scenario to 2050
  - Increased point and non-point nutrients, sediment
  - Increased fishing

Weijerman et al. 2015, PLOS ONE 10:e0144165

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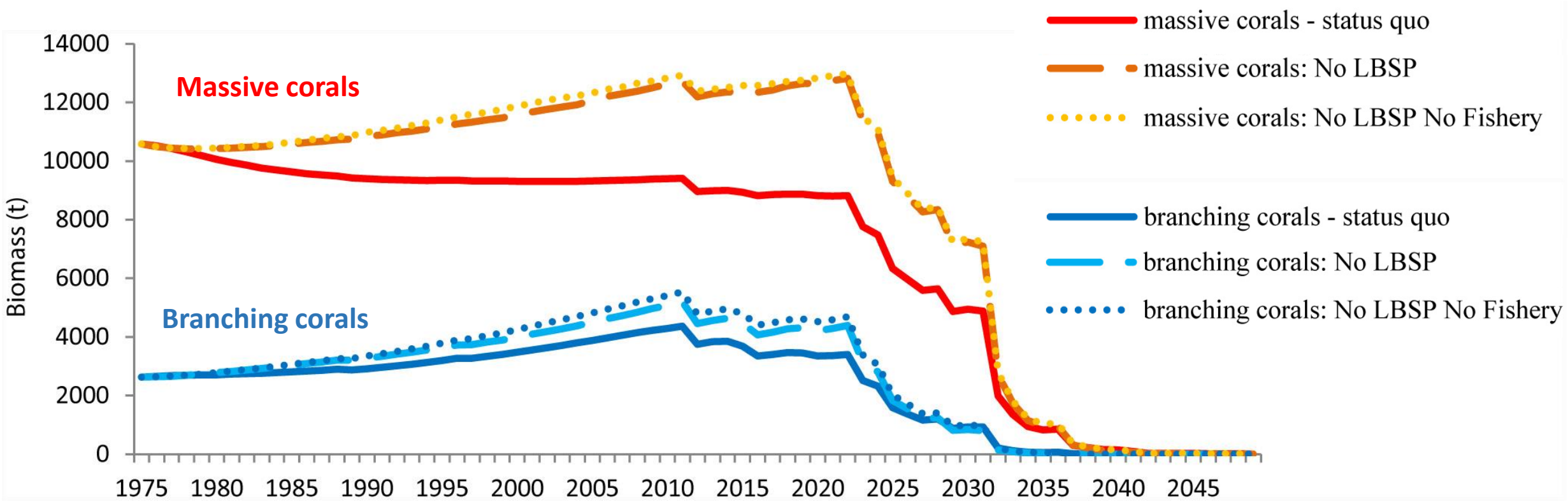
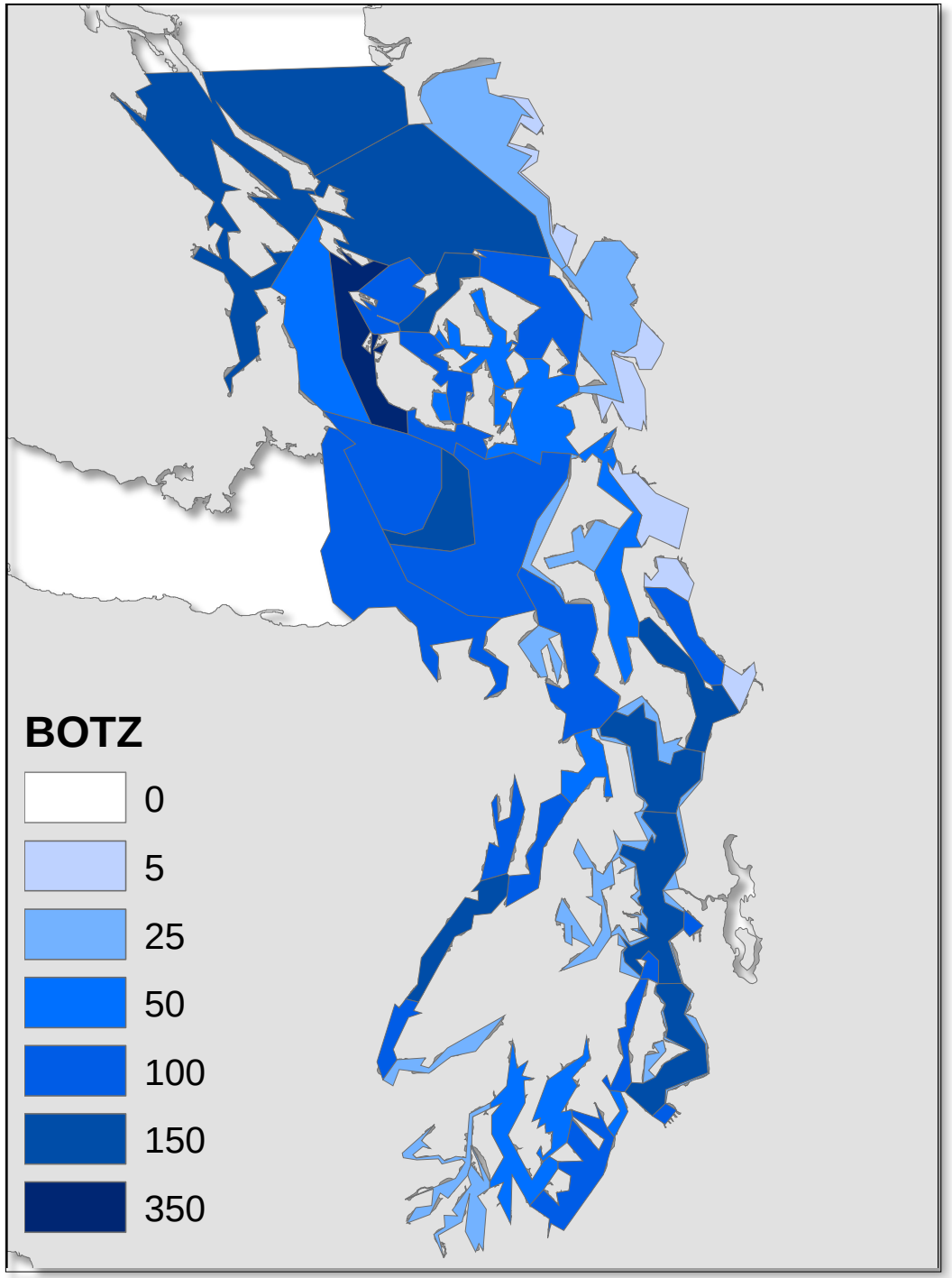


- **Climate change (which causes coral bleaching) becomes increasingly dominant in 2020s**
- **Cutting nutrients and sediment (LBSP; dashed lines) helps, but can't stave off climate effects**
- **Fish production declines too, though sustained somewhat by increases in algal production**

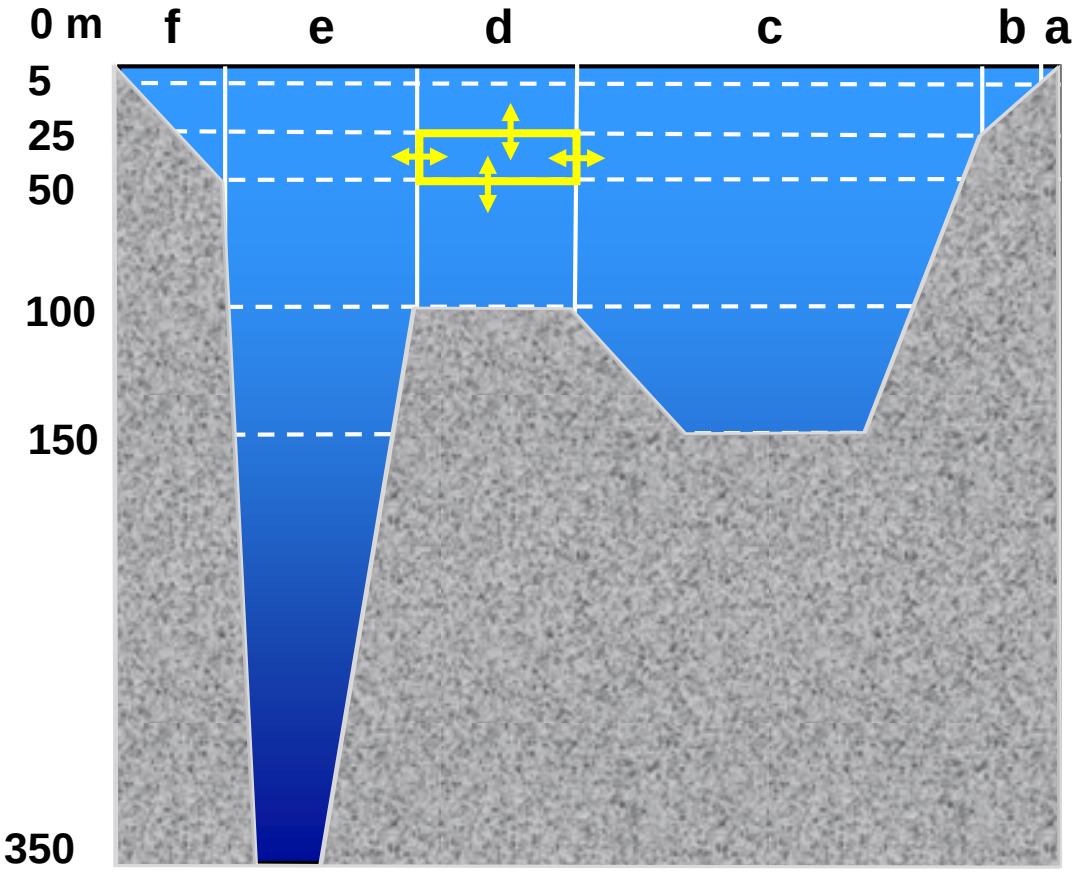
Weijerman et al. 2015, PLOS ONE 10:e0144165

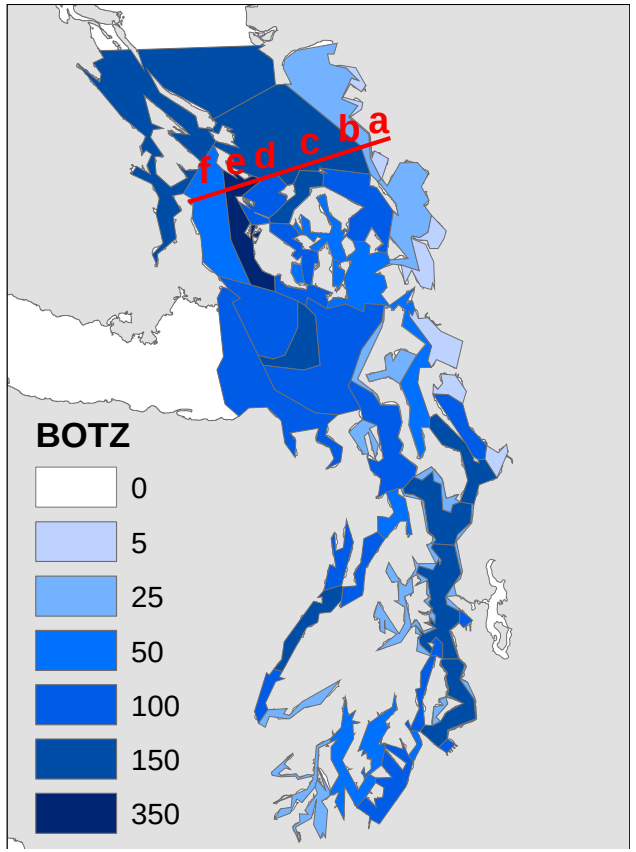
Puget Sound Atlantis model

- 89 polygons, up to 6 depth layers
- ~75 functional groups, from bacteria to whales; 20 different salmon stocks
- Circulation derived from a fine-scale grid-based ROMS model (Parker MacCready, UW)
- Boundary boxes in north and west allow for migratory animals to enter/exit through straits
- Covers marine waters only (below estuarine deltas), but we can simulate riverine inputs of nutrients, sediments, etc.



3-dimensional structure of Atlantis



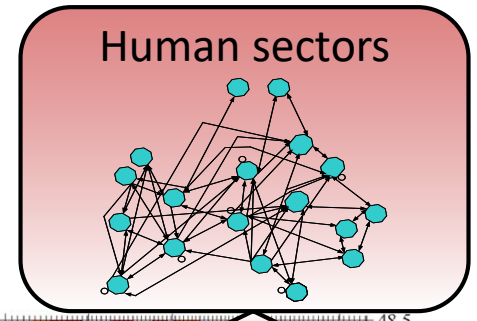


Daily/12h oceanographic fluxes (water, heat, salinity) into, out of each box are controlled by a circulation model

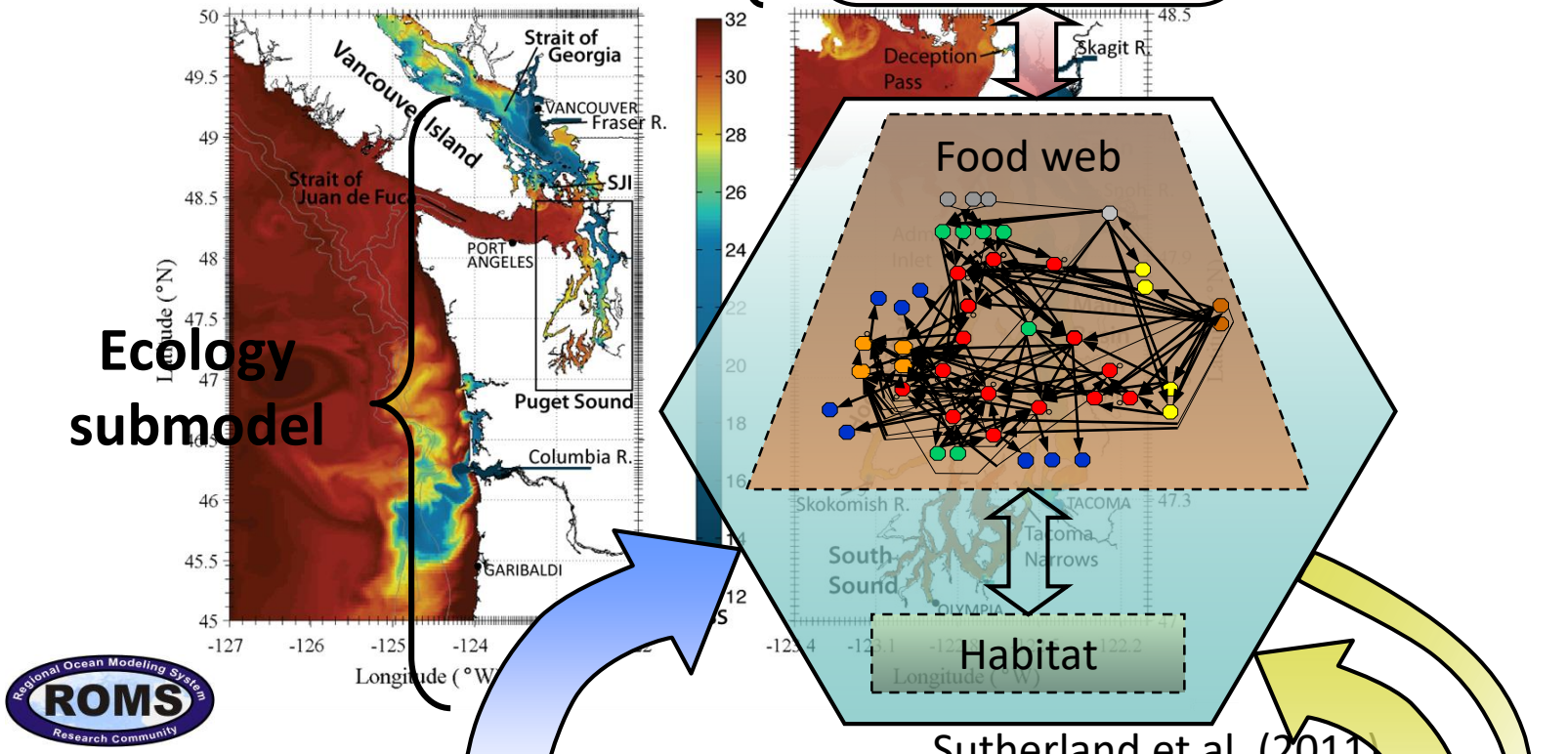
Fulton, E. A. 2004. Ecological Modelling, 173:371-406

Atlantis dynamic structure

Human activities submodel

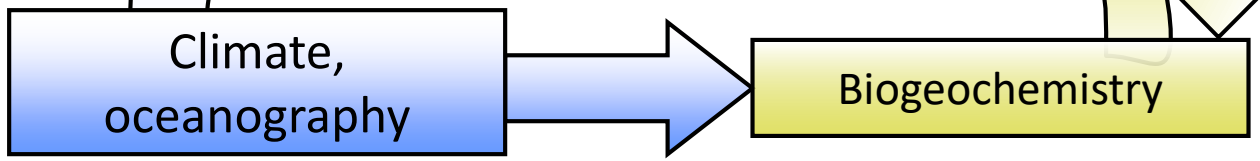


Ecology submodel



Sutherland et al. (2011)

Hydrographic submodel



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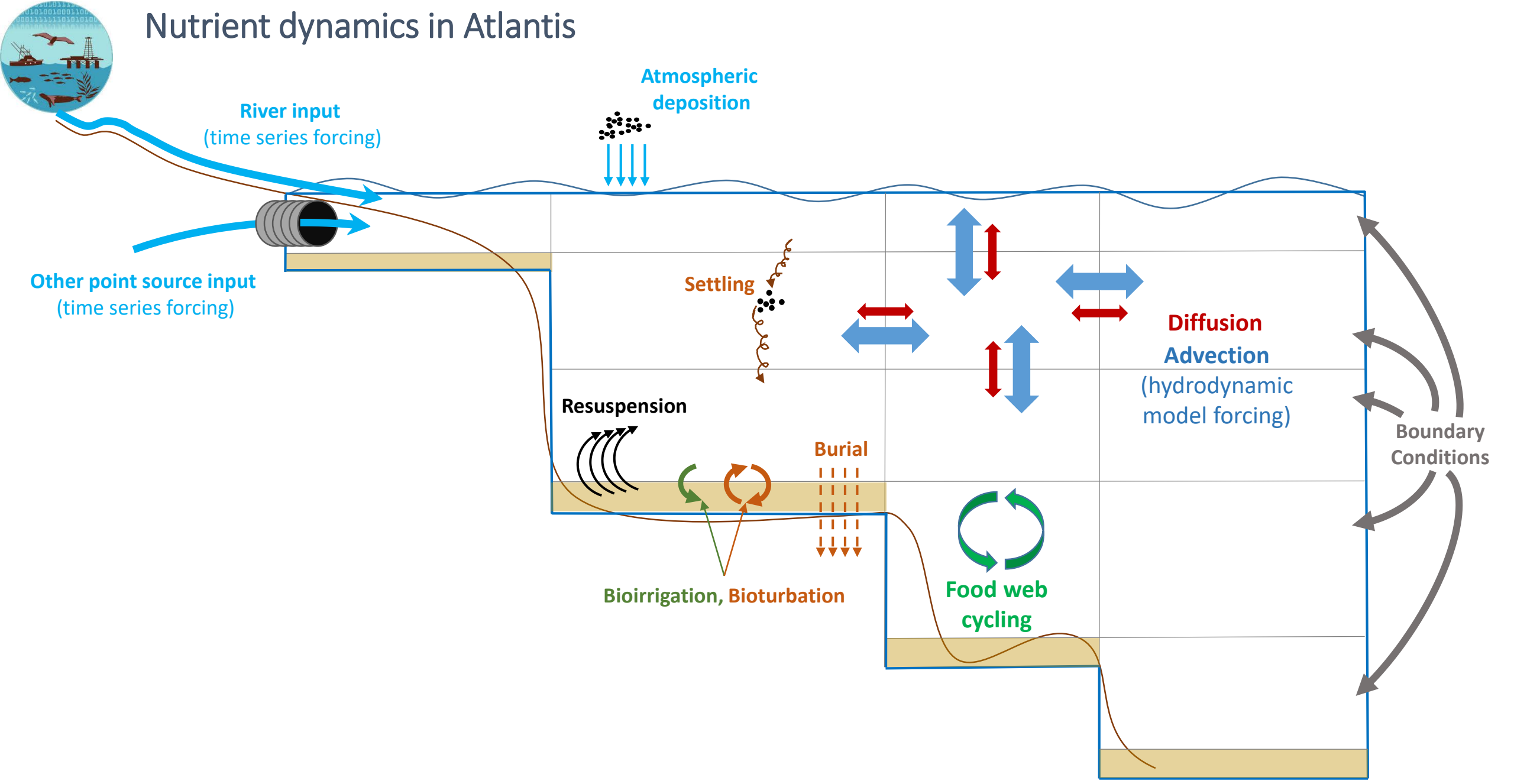
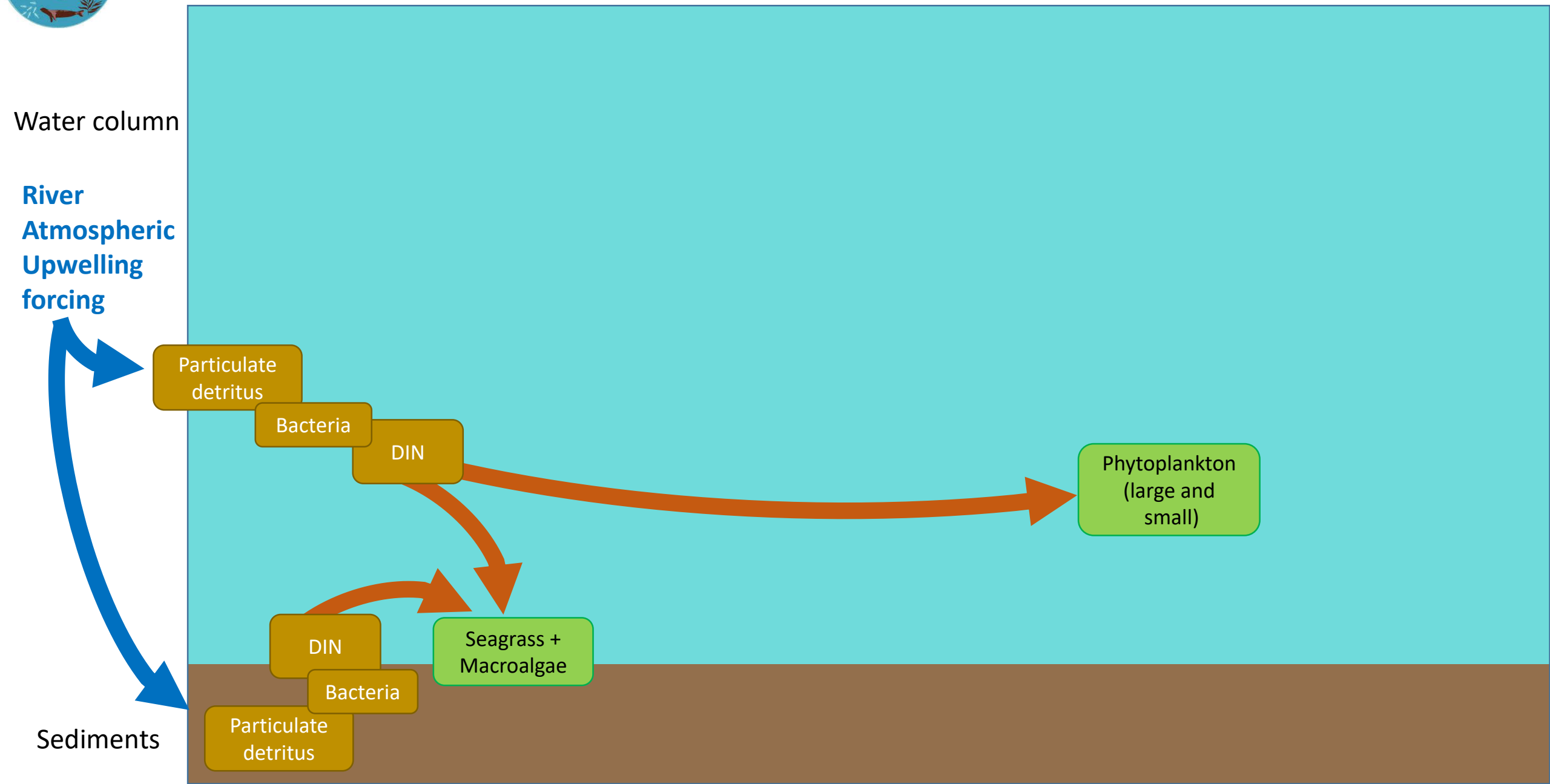
Nutrient dynamics in Atlantis



Audzijonyte, A., Gorton, R., Kaplan, I. and Fulton, E.A. (2017). Atlantis User's Guide Part I: General Overview, Physics & Ecology. CSIRO, Hobart, Australia.

Nitrogen cycling in the food web of the Puget Sound Atlantis Model



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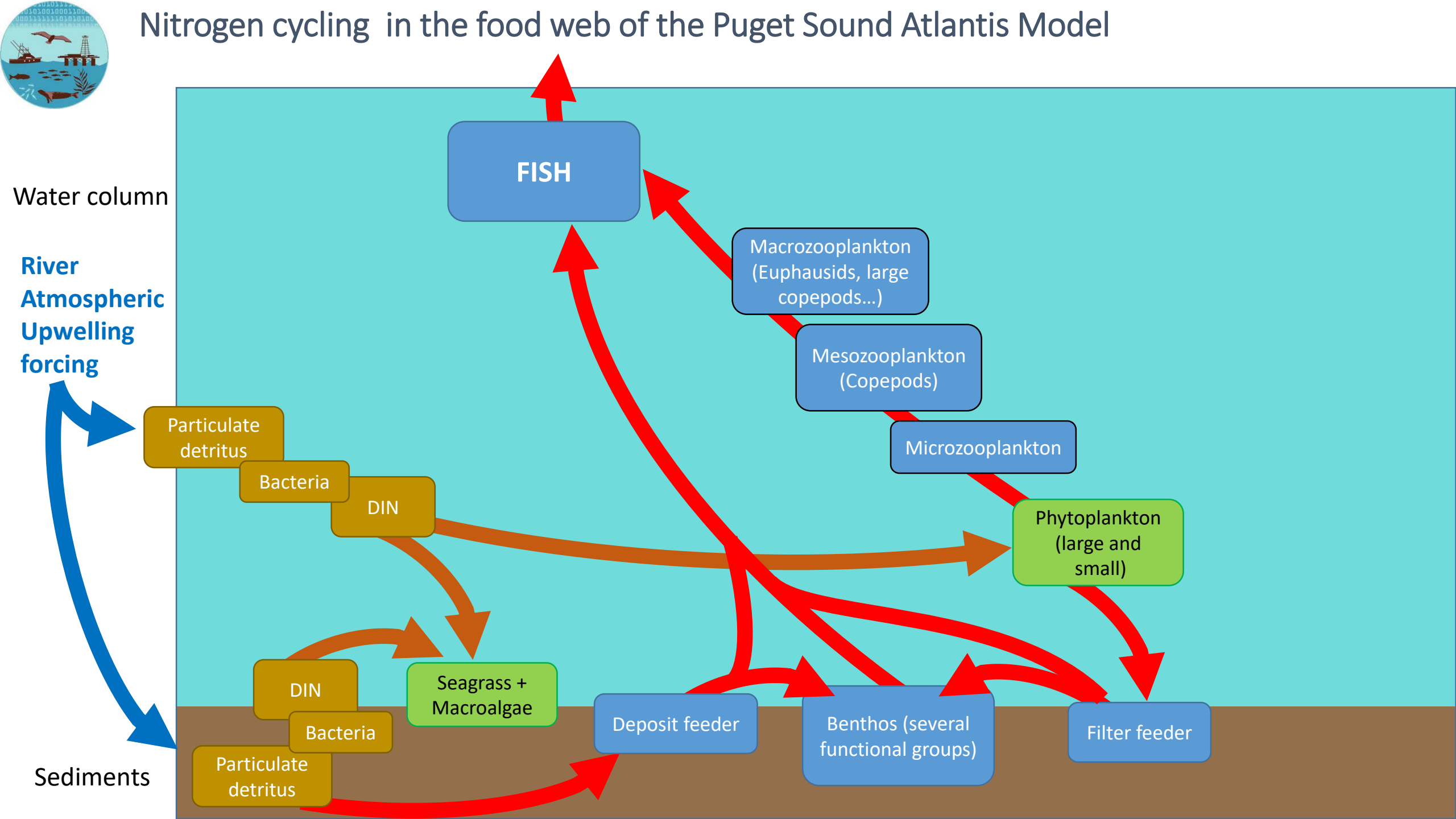

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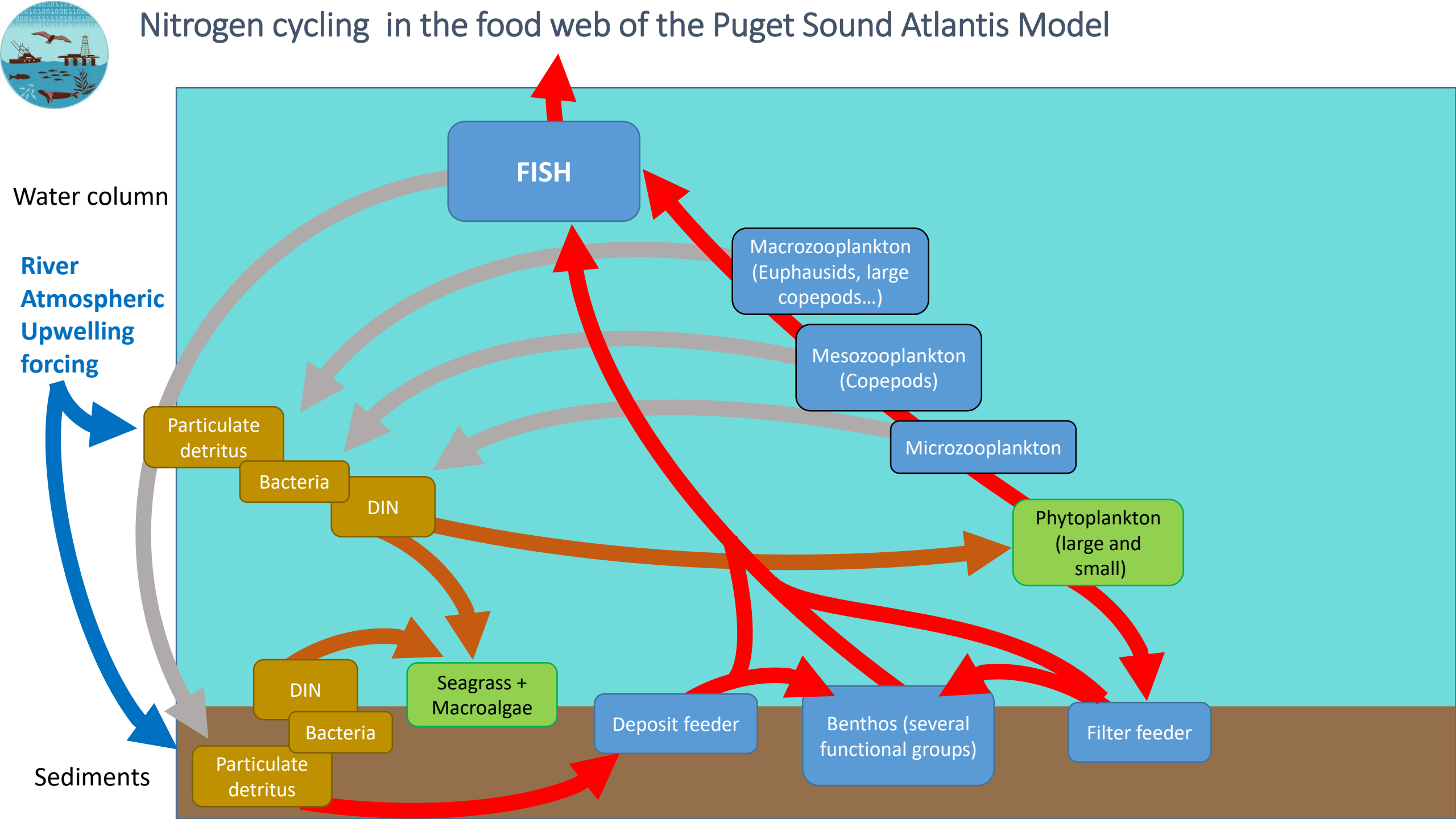

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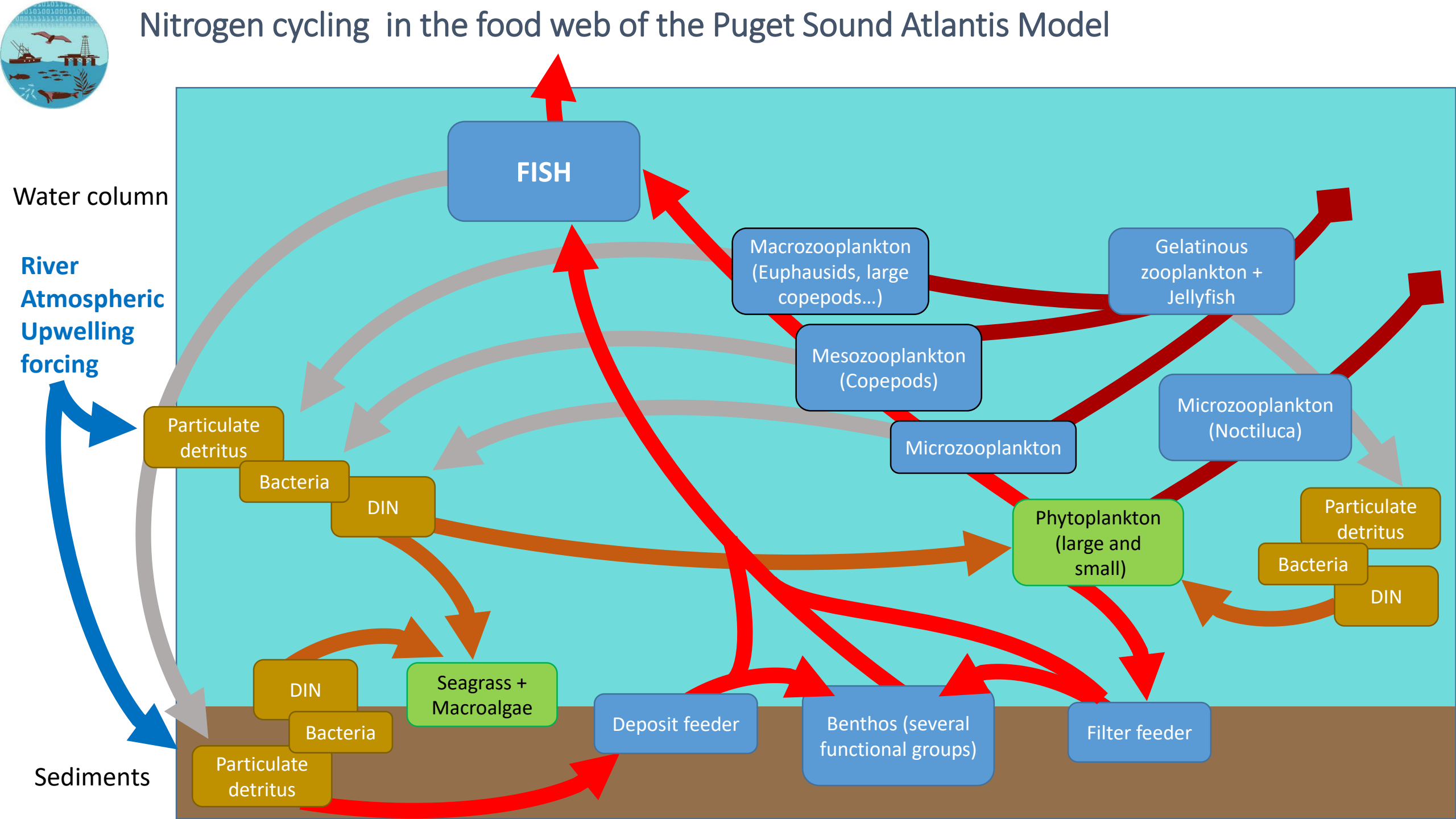
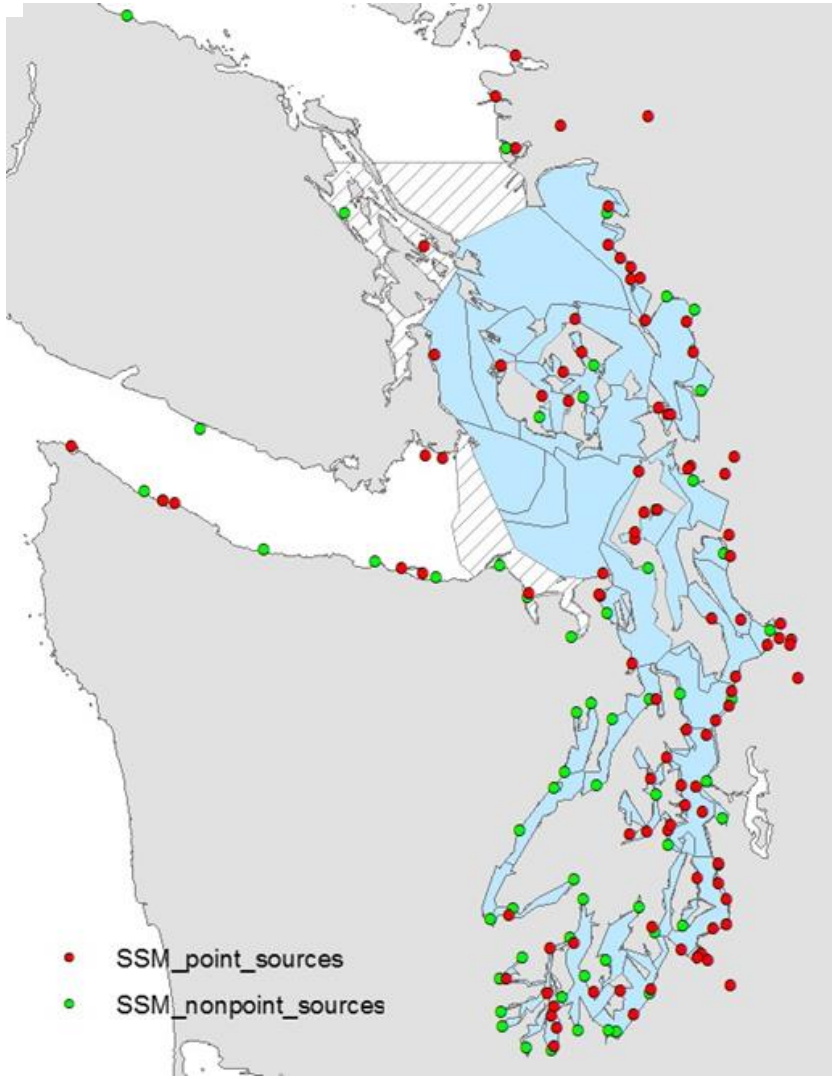
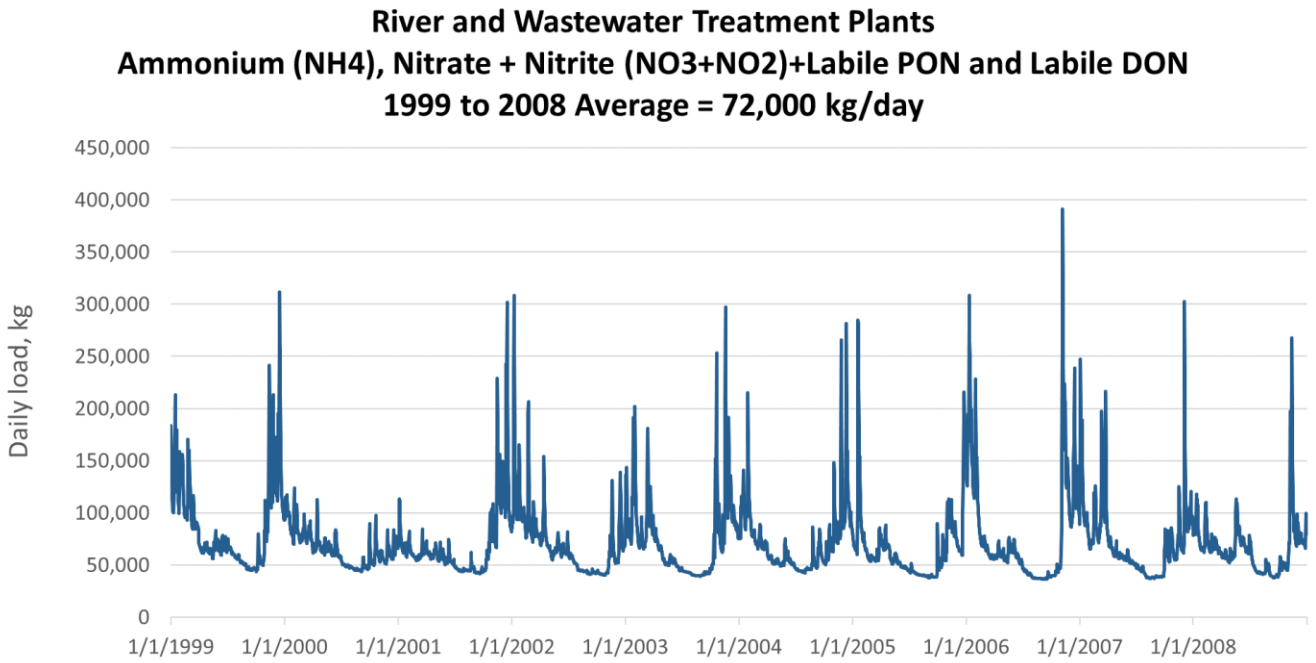


Nutrient input forcing for Puget Sound



River mouth (green) and other point sources (red) (Mohamedali et al., 2011)



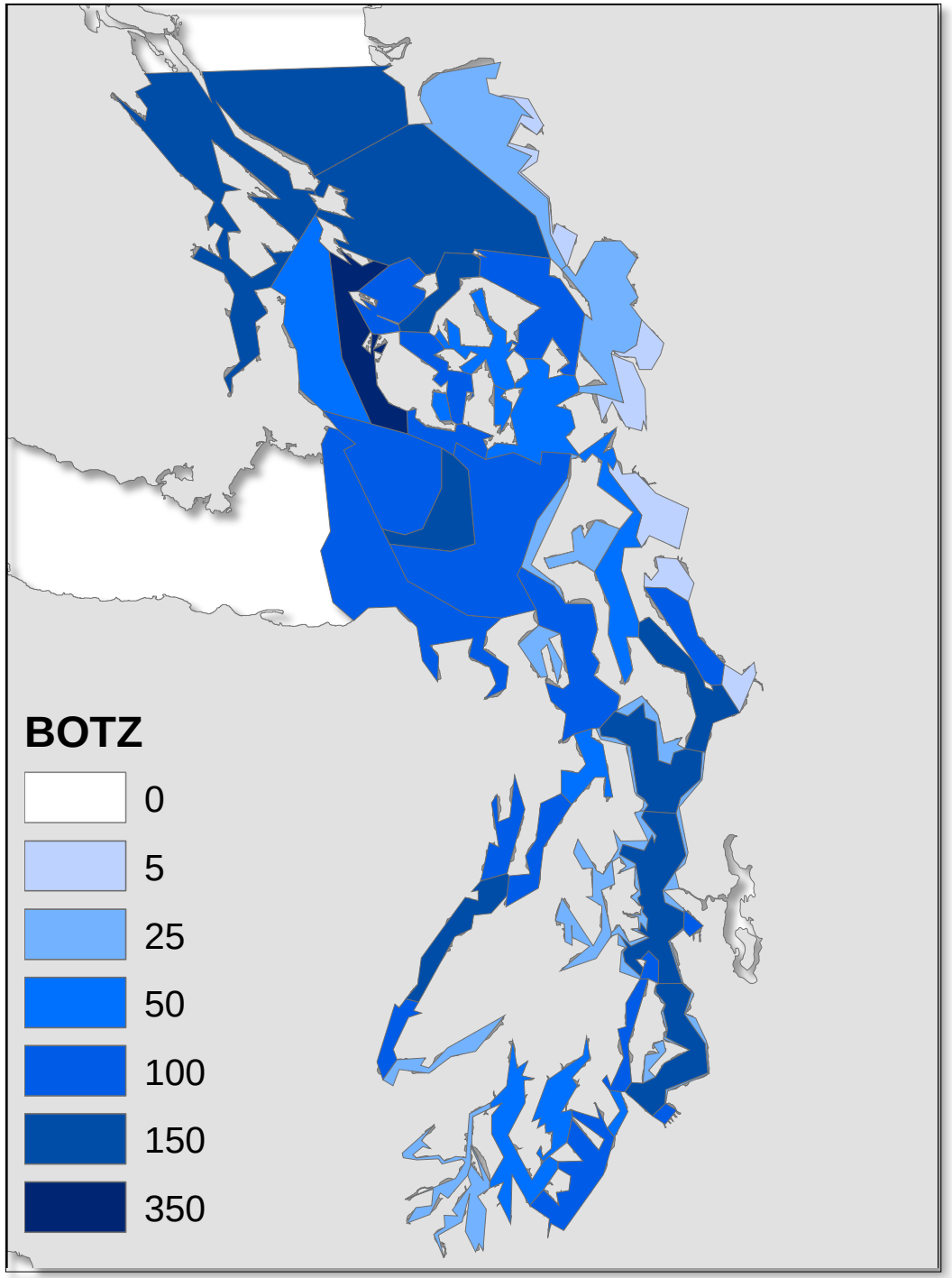
Historical nutrient loading 1999-2008 (Mohamedali et al., 2011)

Mohamedali, T., Roberts, M., Sackmann, B. and Kolosseus, A. (2011) Puget sound dissolved oxygen model nutrient load summary for 1999–2008. 11–03–0 57. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA.

Puget Sound Atlantis model

- Presently we are still in phase of parameter development and will soon begin calibrating model
- Then we will begin simulations focused on factors affecting marine survival of salmon over the past several decades
  - Productivity changes?
  - Stormwater effects (nutrients, turbidity, contaminants)?
  - Changes in lower trophic level pathways?
  - Changes in competition (e.g., pink salmon)?
  - Changes in predation?

- **We welcome ideas (and contexts) for scenarios and key mechanisms!**

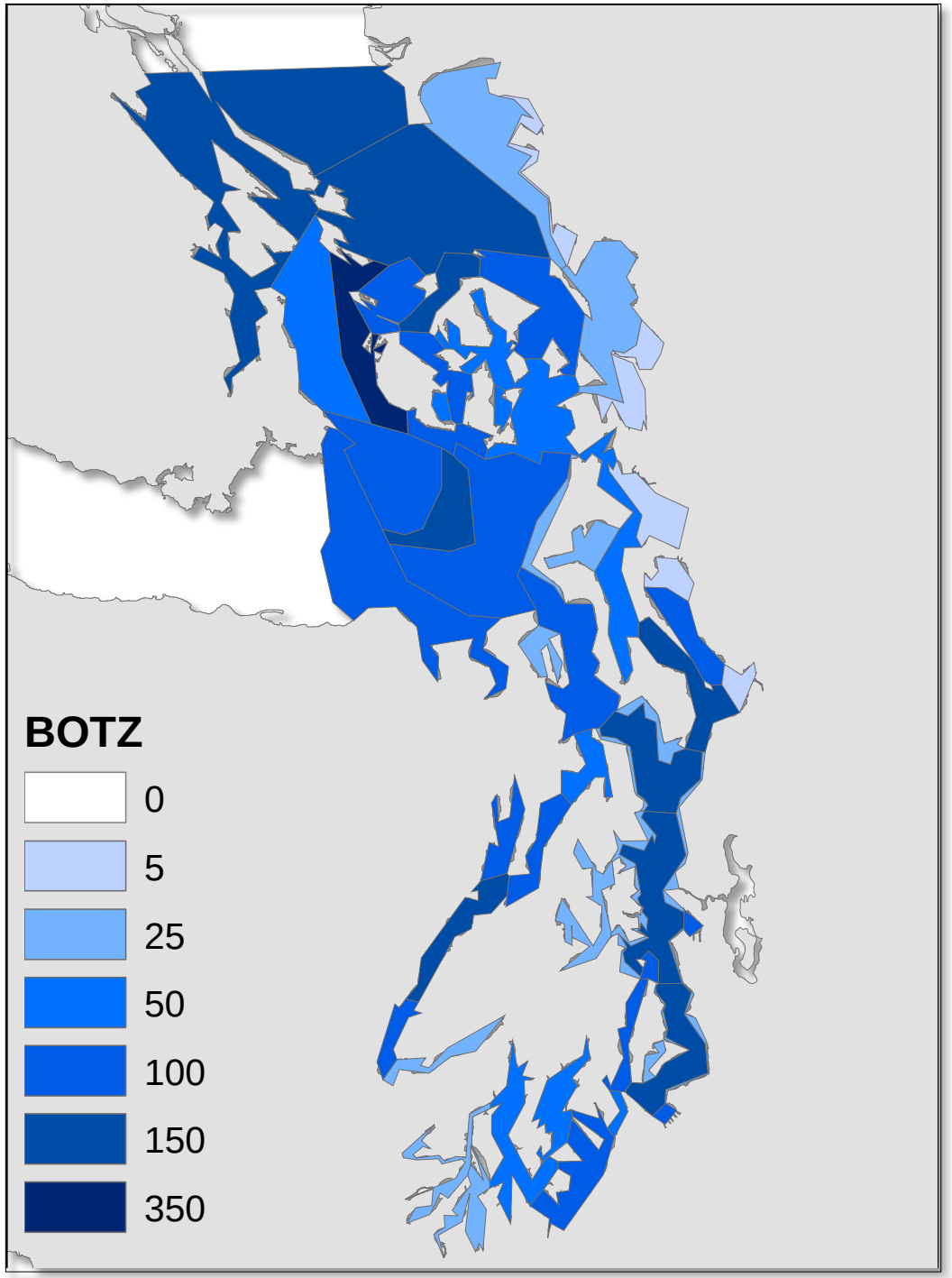


Puget Sound Atlantis model

- This model can also be used in forward "projection" mode to examine future scenarios

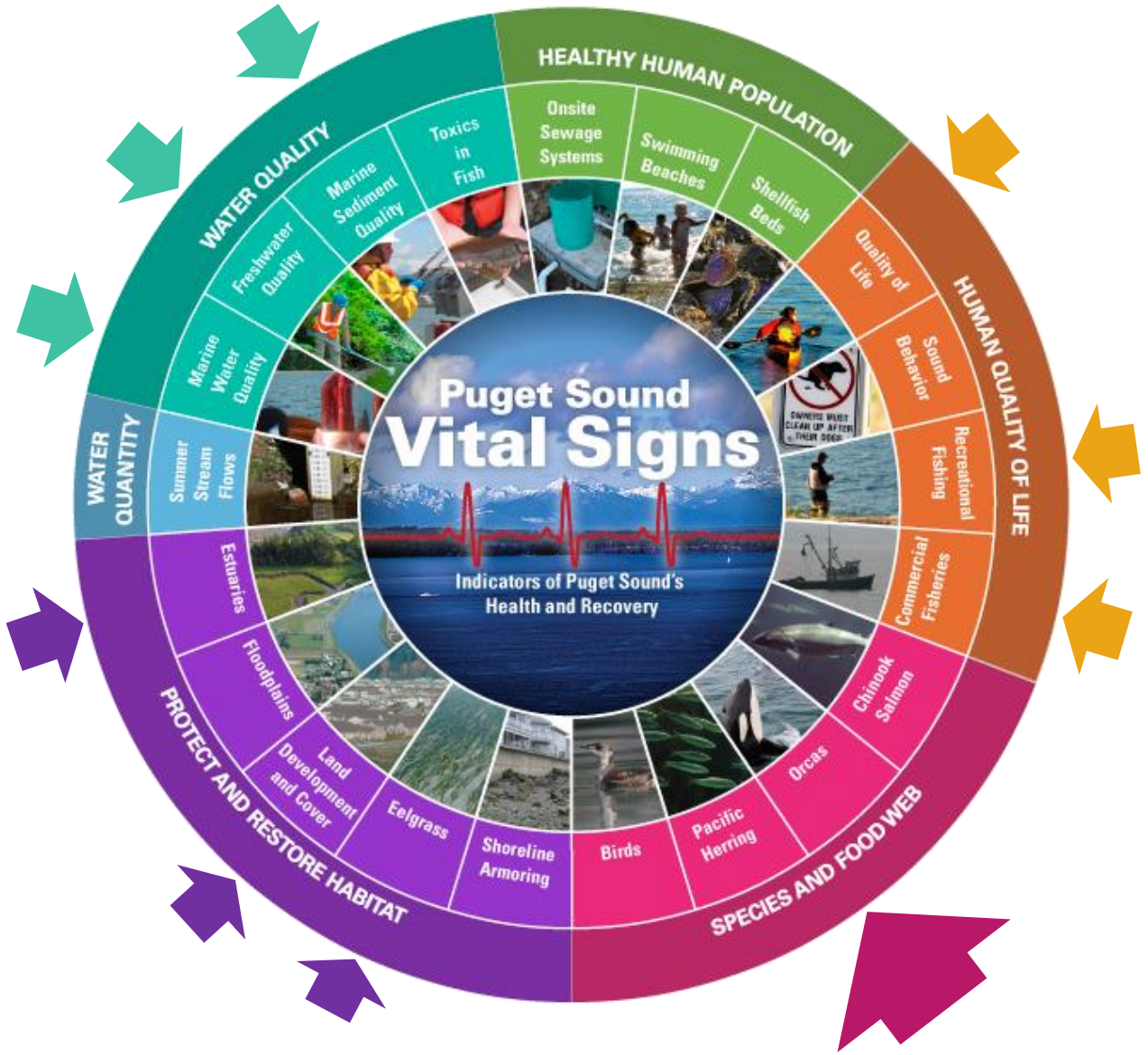
- Example: nutrient loading scenarios out to 2040 and 2070, derived from projections of population growth and climate change-related hydrological and oceanographic changes
  - Roberts et al. 2011, WA Dept of Ecology Pub. 14-03-007

- Model output can also be linked to other model types, e.g., economic input/output models, to extend tradeoffs into socioeconomic domain
  - Kaplan and Leonard 2012, Marine Policy 36:947-954
  - Marshall et al. 2017, Global Change Biology 23:1525-1539



Vital Signs are a comprehensive set of ecosystem management goals and objectives

- *Meeting multiple goals simultaneously is a challenge due to tradeoffs*
- *We are developing a modeling tool that will help address this challenge*



Thanks!

Chris.Harvey@noaa.gov

Or, if you want actual ***good*** answers to any questions you might have, contact Raphael, Isaac and Michael:

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