Interative effects of fishing, ocean acidification and primary productivity change on a marine ecosystem off western Canada

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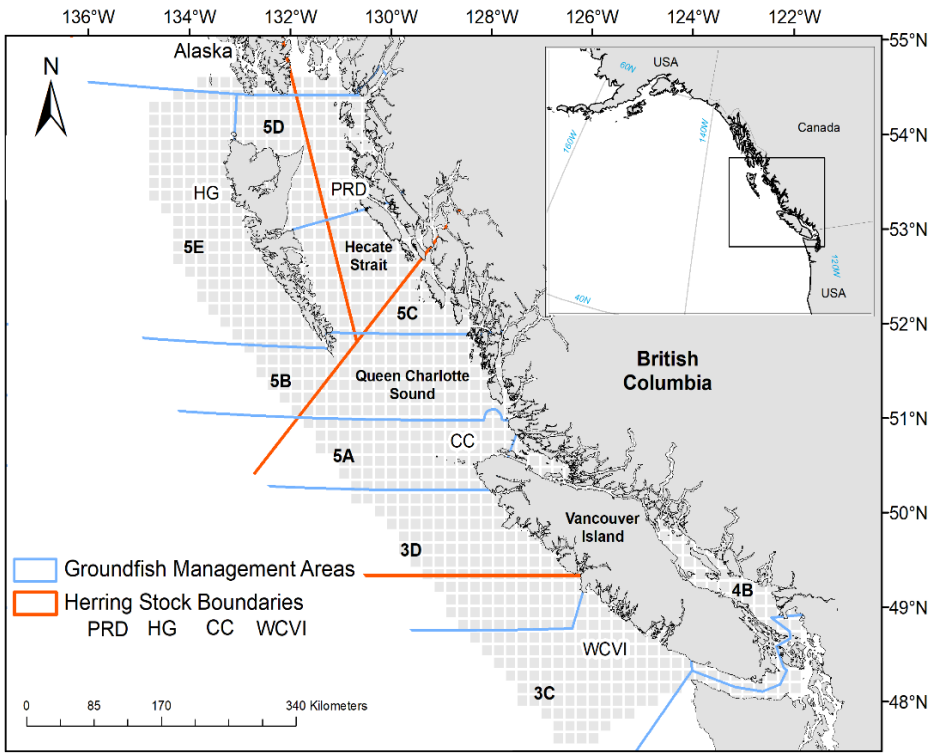
Background

- Marine ecosystems globally are subjected to multiple stressors that have impacted their dynamics both individually and/or cumulatively, and the combined effects of multiple stressors can be either additive, synergistic, antagonistic, or dampened.
- End-to-end (E2E) ecosystem modelling can provide useful numerical laboratories for investigating possible cumulative effects of multiple stressors at community or ecosystem levels, quantify how ecosystems respond over time to multiple stressors, and predict outcomes of different conservation and management scenarios.
- From ecosystem perspectives, quantitative understanding of the combined effects of multiple stressors is crucial for fisheries management and decision-making.

Study area



British Columbia Coast (BC Coast)

- West Coast of Canada
- Pacific Herring (4 major stocks):

Haida Gwaii (HG), Prince Rupert District (PRD), Central Coast (CC), and West Coast of Vancouver Island (WCVI)

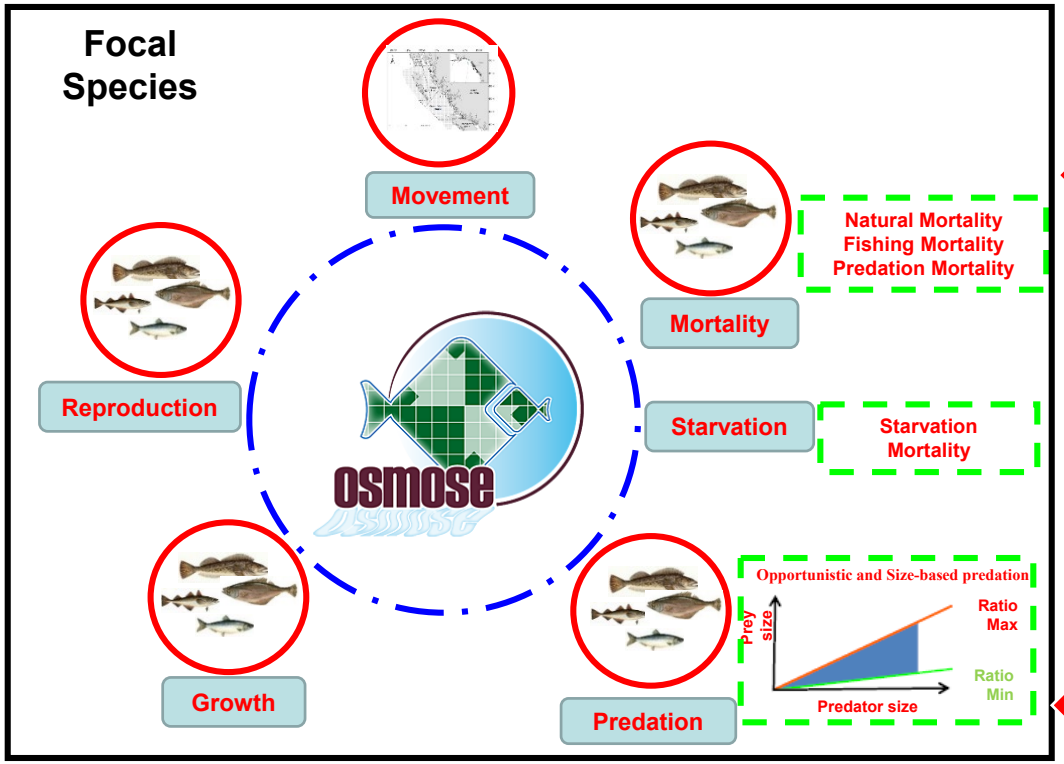
- Groundfish management areas:

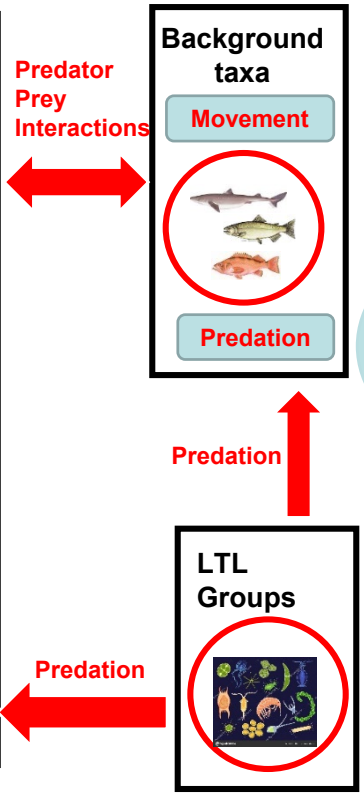
Hecate Strate, Queen Charlotte Sound (5ABCDE, PNCIMA), West Coast of Vancouver Island (3CD,WCVI)

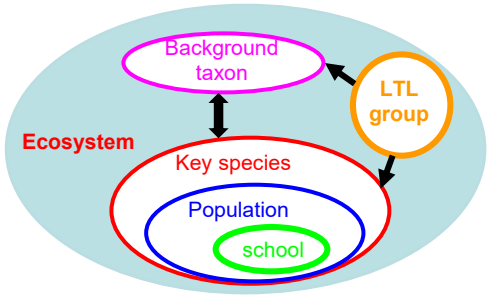
Ecosystem Model

OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation)

Shin & Cury 2001, Aquat. Living Resour.; Fu et al. 2013. Prog Oceanogr.







Fu et al. 2017. ICES J. Mar. Sci.

OSMOSE-BC

- **Model components**: **14** focal species (stocks), **17** background taxa and **2** plankton groups.
- **Focal species**: Pacific Herring (*Clupea pallasii*), Pacific Cod (*Gadus macrocephalus*), Lingcod (*Ophiodon elongatus*), Arrowtooth Flounder (*Atheresthes stomias*), Walleye Pollock (*Theragra chalcogramma*), Pacific Halibut (*Hippoglossus stenolepis*) Steller Sea Lions (Eumetopias jubatus) and Euphausiids (*Thysanoessa spp.* and *Euphausia spp.*).
- **Model validation**: OSMOSE-BC was constructed and validated using available stock assessment data for Pacific Herring, Pacific Cod, Lingcod, Arrowtooth Flounder and Walleye Pollock.






Simulation scenarios

- We hypothesized 3 main stressors that take place both individually and interactively on the BC ecosystem: Fishing (F), Ocean Acidification (OA), and Primary Productivity change (PP).
- Different stressors mainly affect on different functional groups with various forcing types:

  F: Focal fish species (Fishing mortality forcing)

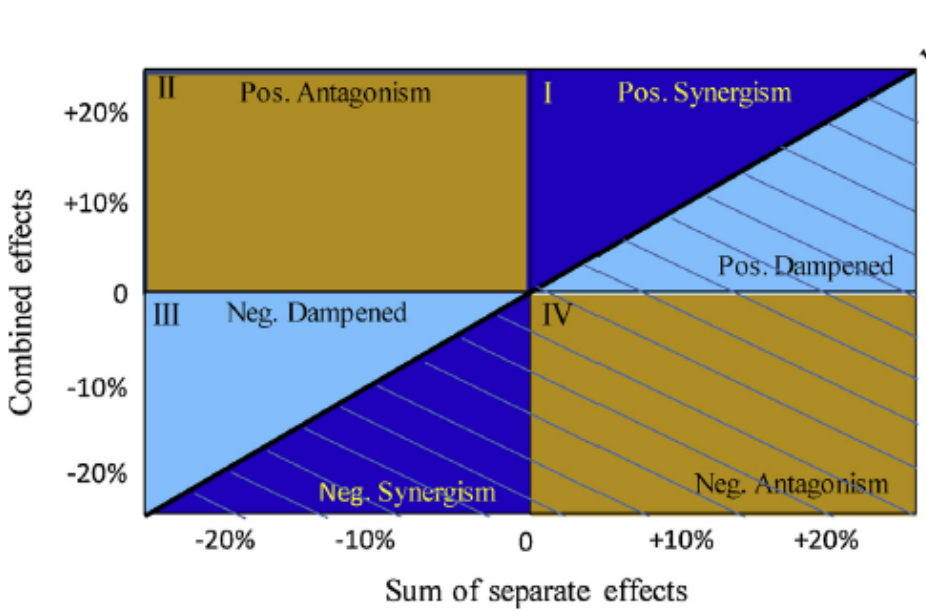
  OA: Euphasiids (Larval mortality forcing)

  PP: Phytoplankton (Biomass forcing)
- Multipliers were used to model the different levels of effects

  F : {0.5,0.75,1.0,1.25,1.5}; OA: {1.05,1.10,1.0,1.15,1.20}; PP: {0.5,0.8,1.0,1.2,1.5}

  Multiplier of 1.0 corresponds to the baseline scenario.
- Ecological indicator: biomasses of focal species were summed for the analyses.

Cumulative effects



Combined versus additive separate effects.
Source: Fu et al. 2018. Ecol. Model.

ΔV_k^{Com} >0, ΔV_k^{Sep}>0, ΔV_k^{Com} >ΔV_k^{Sep} Positive Synergistic (Pos_Syn)

ΔV_k^{Com} >0, ΔV_k^{Sep}>0, ΔV_k^{Com} <ΔV_k^{Sep} Positive Dampened (Pos_Dam)

ΔV_k^{Com} <0, ΔV_k^{Sep}<0, ΔV_k^{Com} <ΔV_k^{Sep} Negative Synergistic (Neg_Syn)

ΔV_k^{Com} <0, ΔV_k^{Sep}<0, ΔV_k^{Com} >ΔV_k^{Sep} Negative Dampened (Neg_Dam)

ΔV_k^{Com} >0, ΔV_k^{Sep}<0, Positive Antagonistic (Pos_Ant)

ΔV_k^{Com} <0, ΔV_k^{Sep}>0, Negative Antagonistic (Neg_Ant)

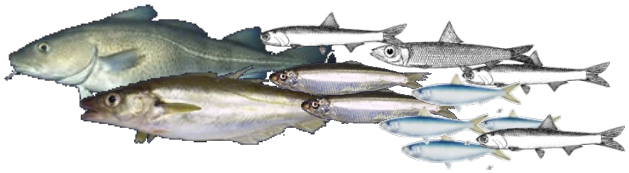
ΔV_k^{Com}, represents the biomass/yield changes of scenario k which contains more than 1 stressors from the baseline control scenario

ΔV_k^{Sep} represents the sum of biomass/yield changes with each of the stressors varying independently.

Risky effects : Positive Dampened, Negative Synergistic, Negative Antagonistic

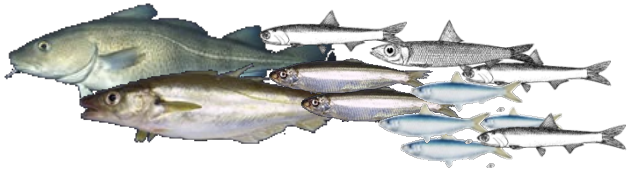
Non-Risky effects: Positive Antagonistic, Positive Synergistic, Negative Dampened

Characterize the fishing-climate interactions



Fu et al. 2018. Ecol. Model.

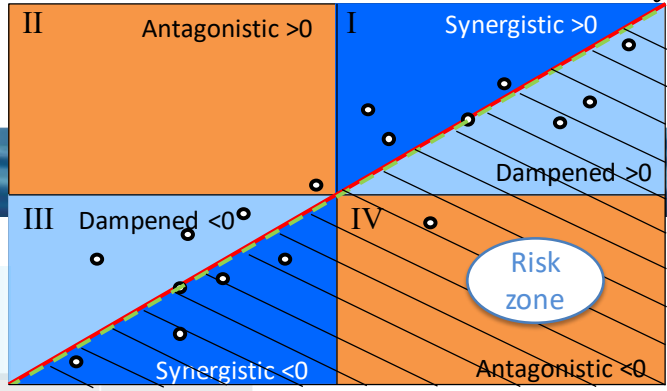
Characterize the fishing-climate interactions



Fu et al. 2018. Ecol. Model.

To define the combined effects more specifically, we consider both the magnitude and response direction of being either positive or negative.

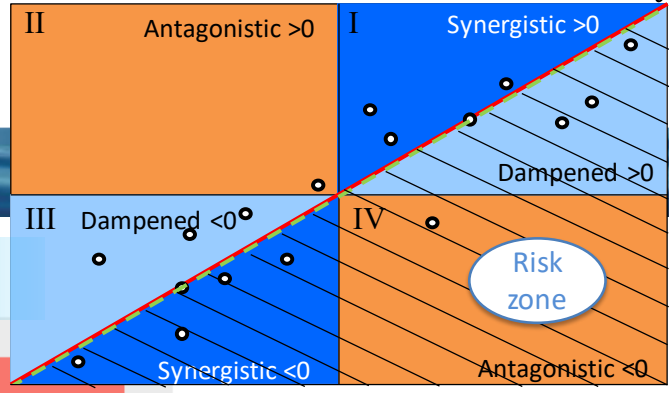
Results



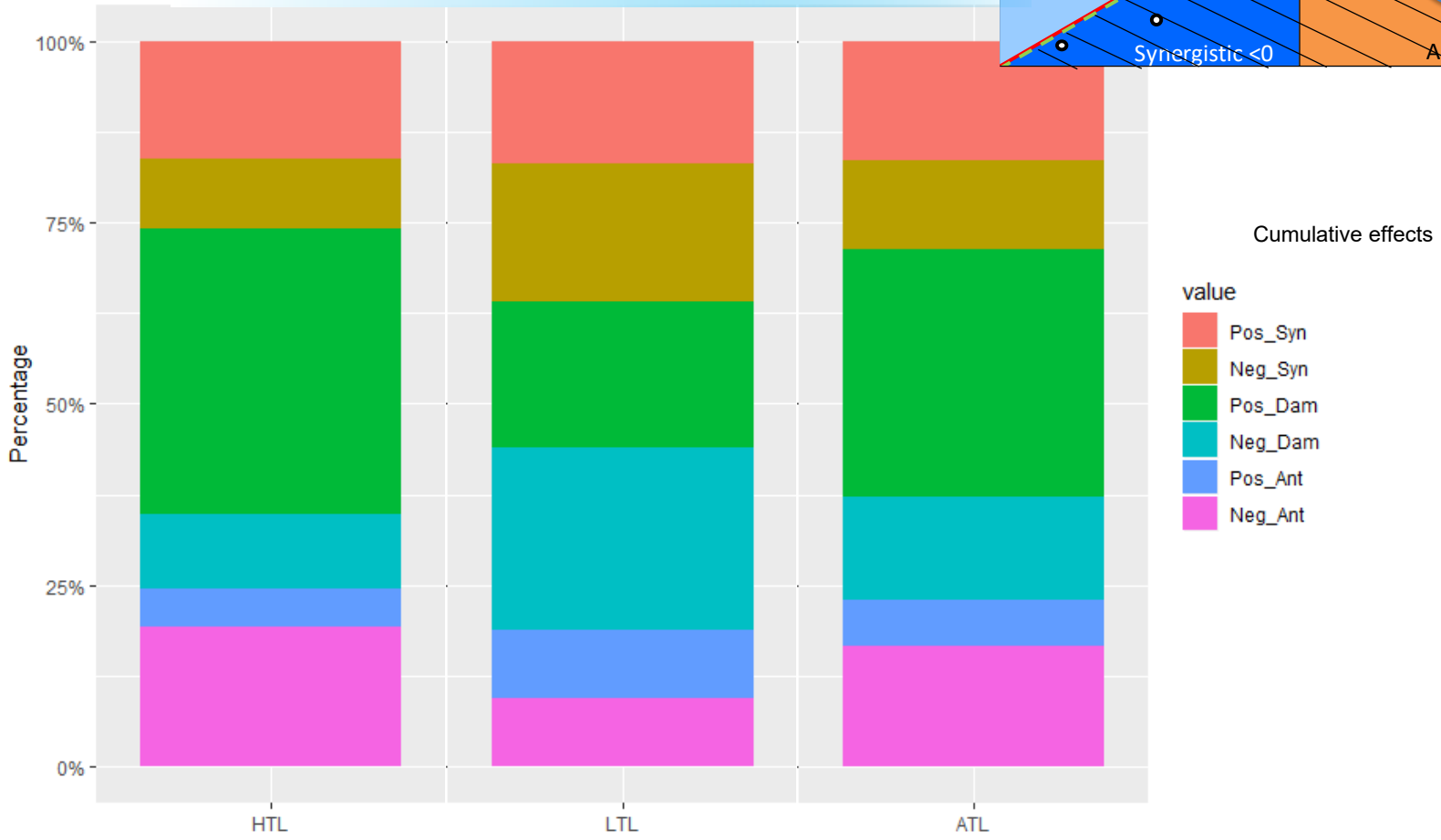
Combined effects: Frequency

Interactive effects (%) under multiple stressors

- Dampened effects are more dominant than synergistic and antagonistic effects.
- Positive Dampened is the most frequent effect under all combinations of stressors.



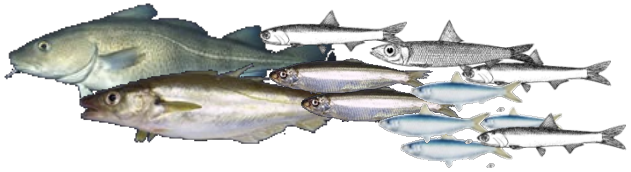
Combined effects: Frequency



Interactive effects (%) on different trophic groups

- Dampened effects are more dominant than synergistic and antagonistic effects.
- HTL is subjected more to positive than negative dampened, while LTL more to negative.

Combined effects: Frequency vs intensity



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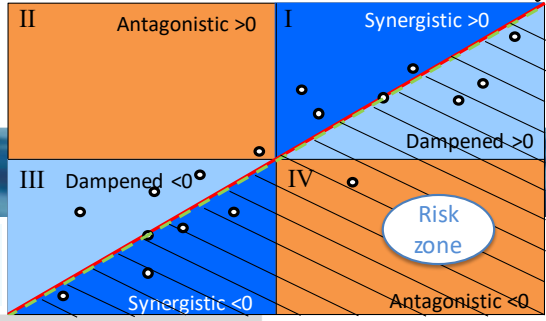
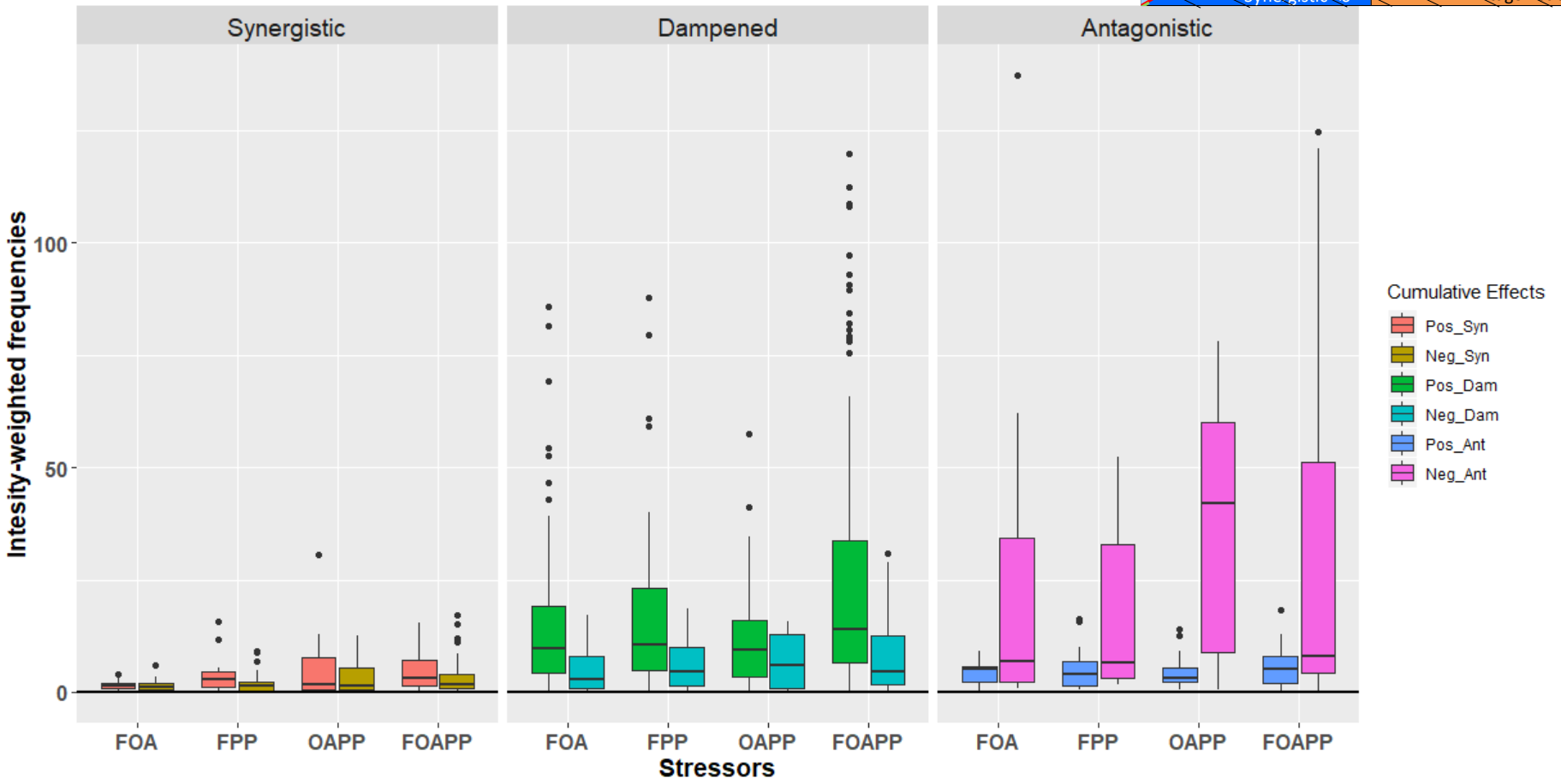
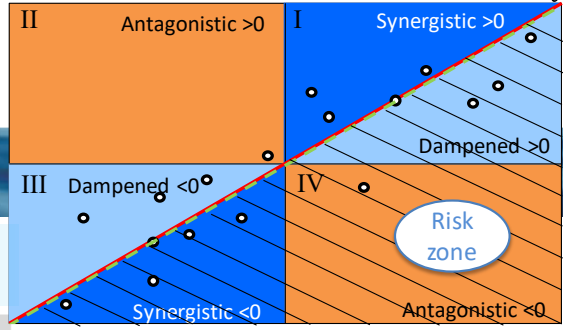


Combined effects: Intensity-weighted frequency

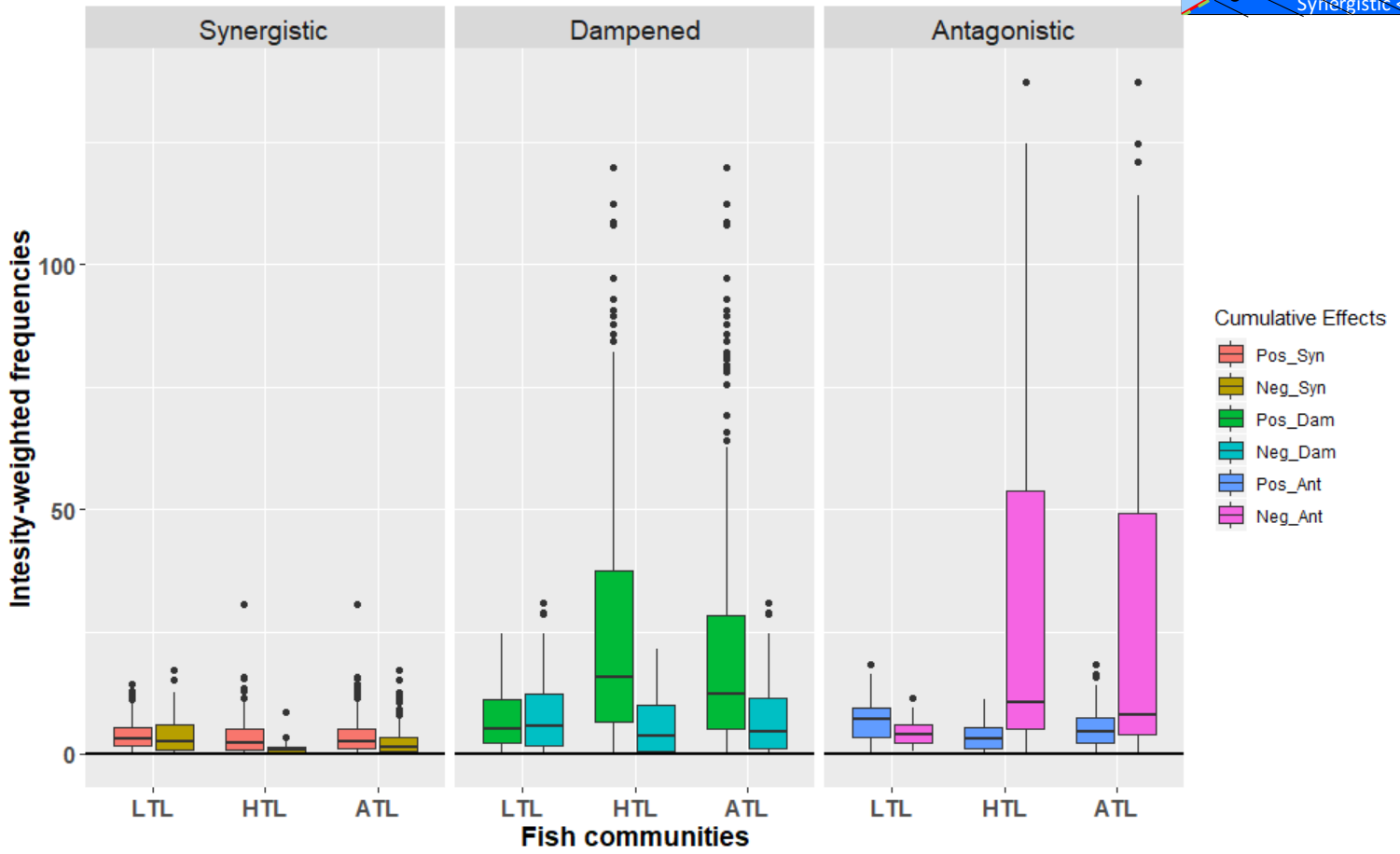


Intensity-weighted frequency of interactive effects under multiple stressors

- For synergistic and dampened effects, it is more likely to be positive than negative;
- For antagonistic effect, it is more likely to be negative than positive.

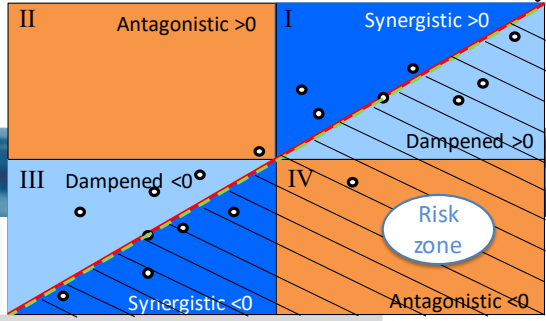


Combined effects: Intensity-weighted frequency

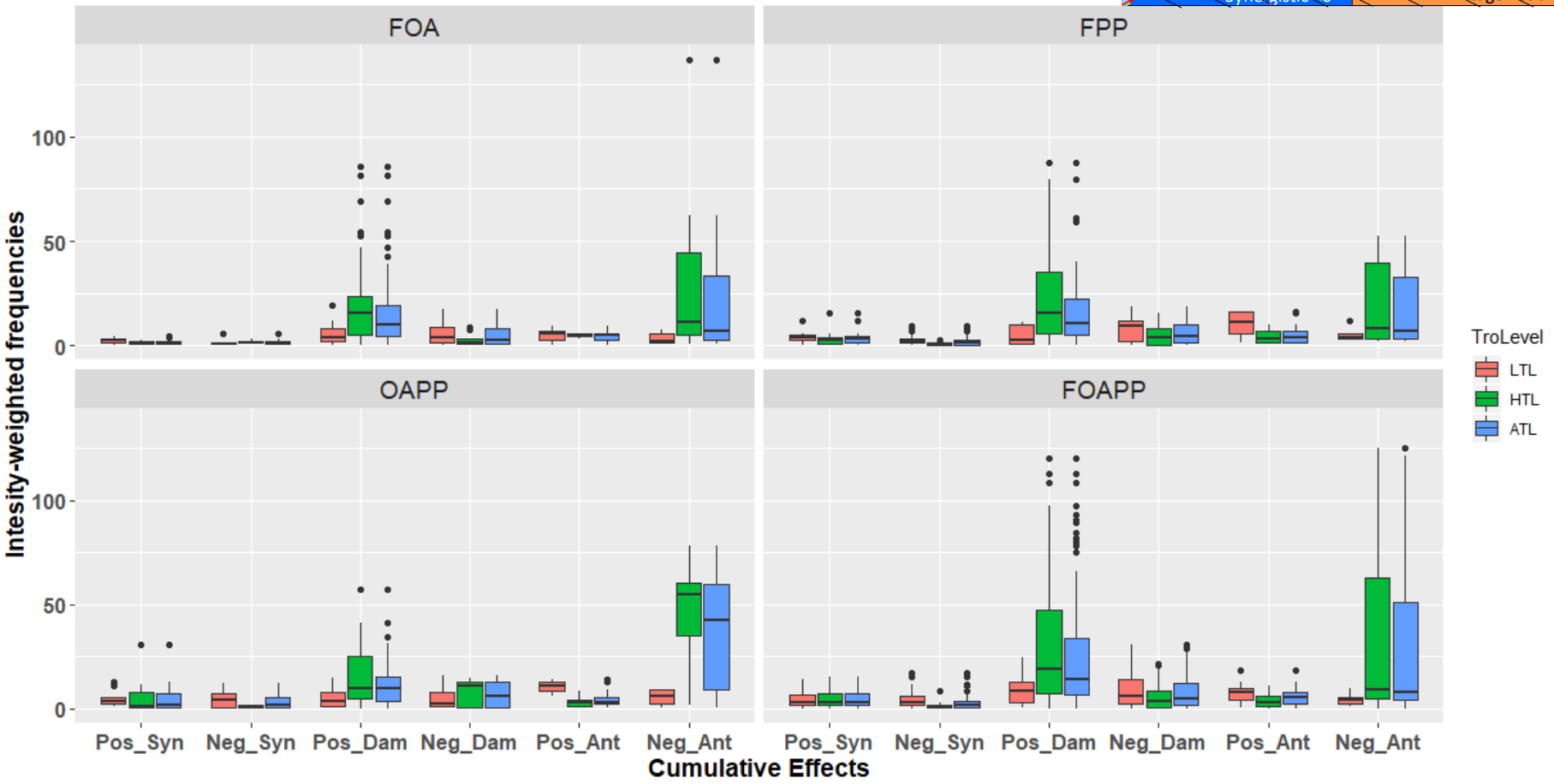


Intensity-weighted frequency of interactive effects on different trophic groups

- For synergistic and dampened effects, it is more likely to be positive than negative;
- For antagonistic effect, it is more likely to be negative than positive for HTL and ATL.



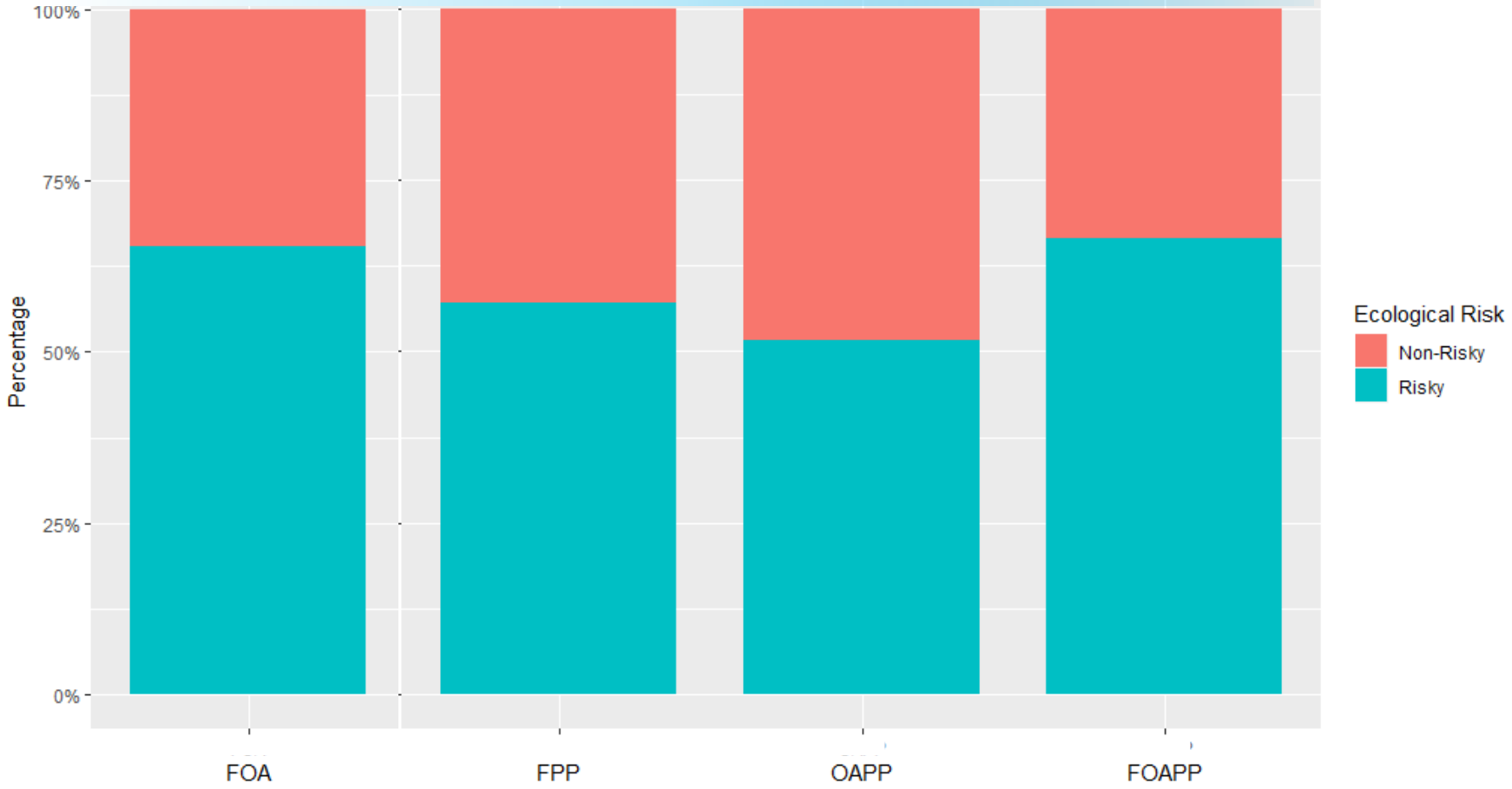
Combined effects: Intensity-weighted frequency



Intensity-weighted frequency of interactive effects

Across all combinations of stressors, positive dampened and negative antagonistic are the dominant types of cumulative effects.

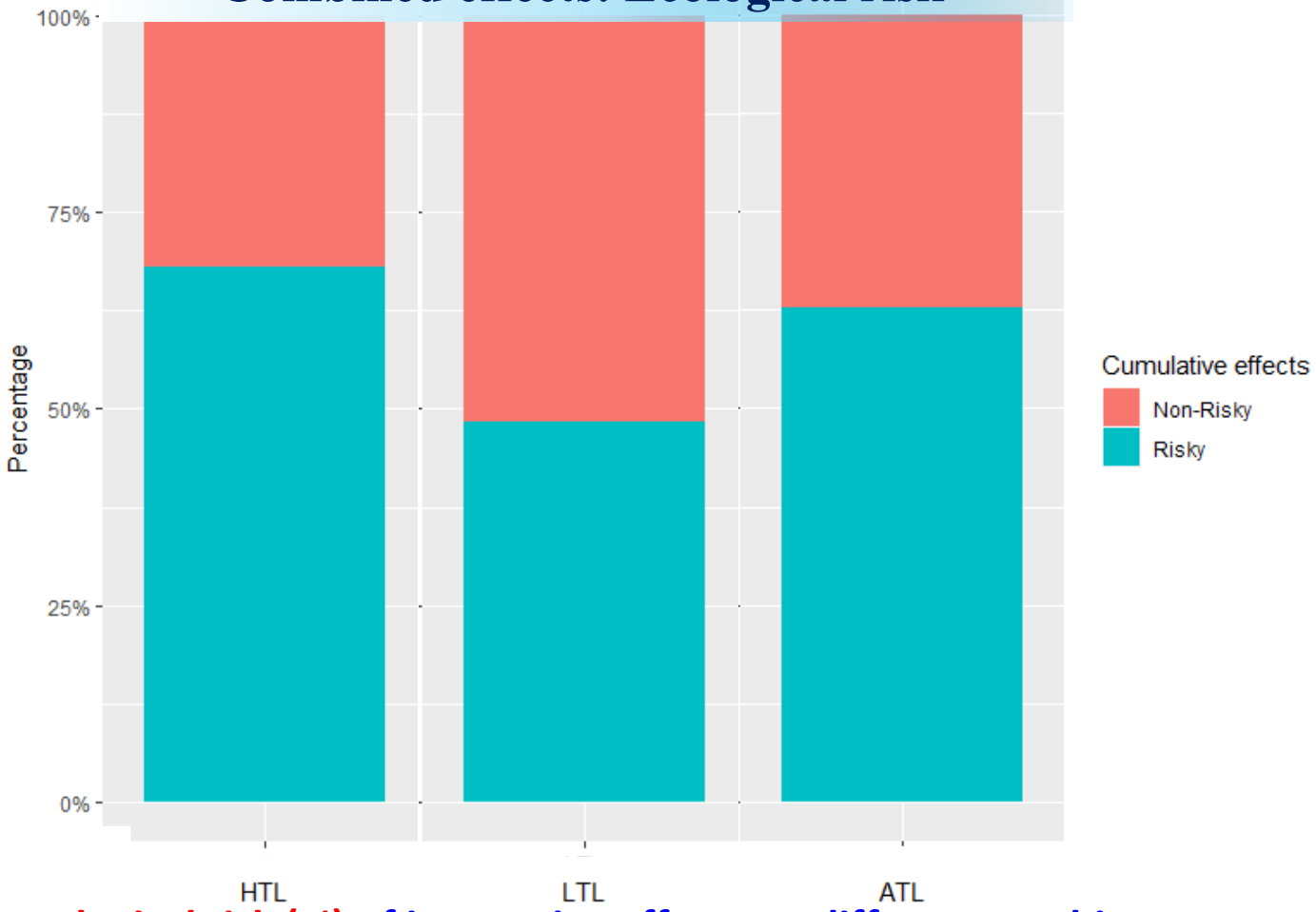
Combined effects: Ecological risk



Ecological risk (%) of interactive effects under different combination of stressors

- Multiple stressors tend to have higher frequency of risky effects than non-risky effects.
- Three-stressor scenario has the highest frequency of risky effects.

Combined effects: Ecological risk



Ecological risk (%) of interactive effects on different trophic groups

Among all fish communities, LTL group has the lowest risky effects while HTL has the highest.

Results and Discussion

1. Different trophic levels of fish communities (i.e., HTL, LTL, ATL) showed varying responses to different stressors.
2. Across all interactive effects, Dampened effects are more common than Antagonistic and Synergistic effects under multiple stressors.
3. Further analyses suggest that Positive Dampened and Negative Antagonistic are the main interactive effects according to the intensity-weighted frequencies across all combinations of multiple stressors.
4. Positive Dampened and Negative Antagonistic may cause risky ecological effects, which may warrant more attention in the future management of fisheries and ecosystems.

Acknowledgements

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Thank you!

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