International Copper Association
Copper Alliance

Due Diligence Investigations of Novel Copper-alloy Mesh Materials in Aquaculture:

- Measured copper release rates
- Modeled and measured ambient concentrations
- Measured uptake in cultured fish
- Predicted bioavailability to other aquatic organisms

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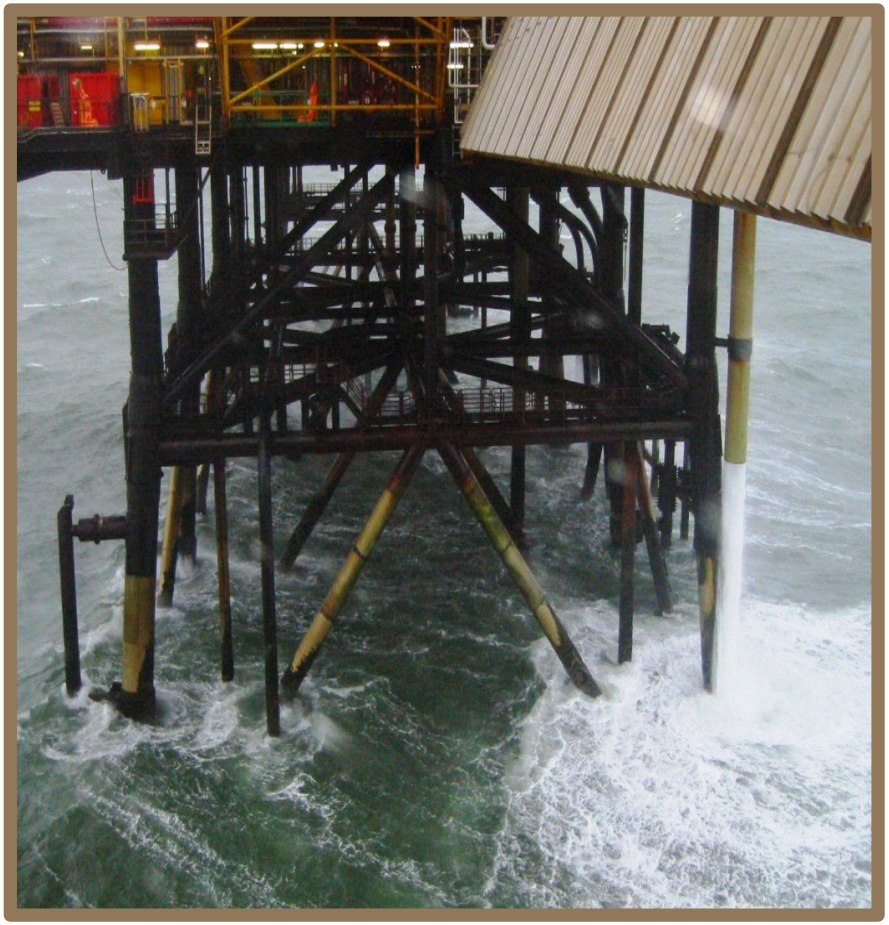
Why copper alloys?

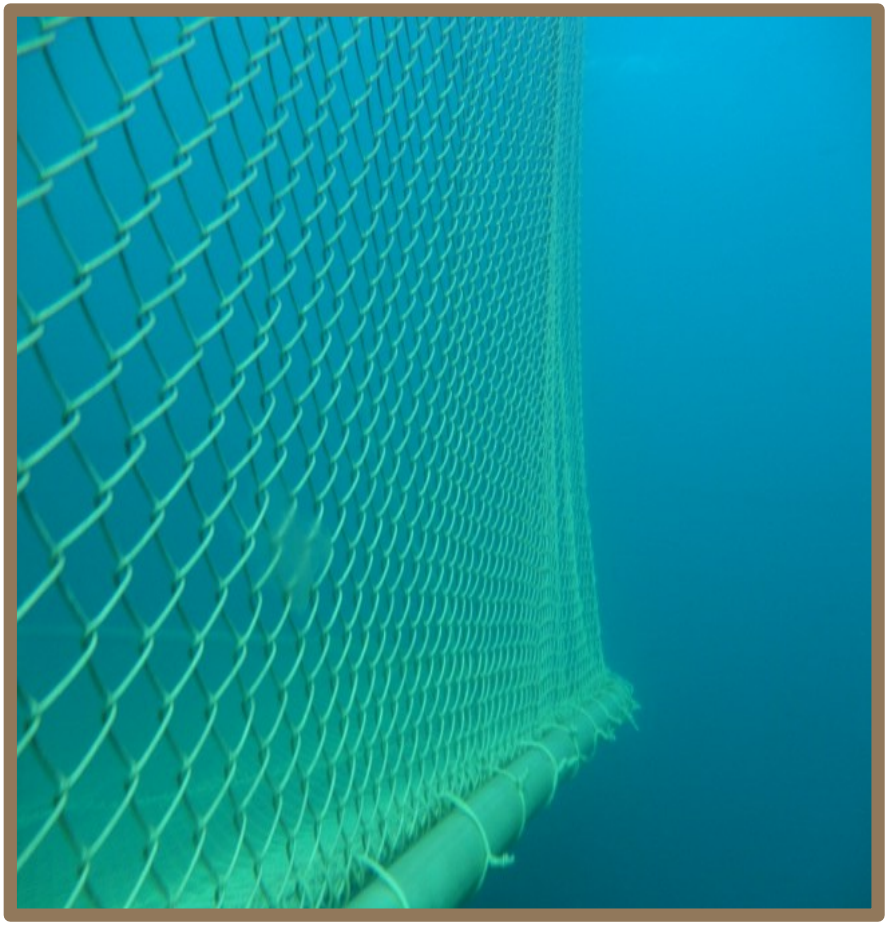
Cu

- Durable in the offshore environment
- Solid track record in marine engineering
- Low corrosion rates
- Strong and rigid
- Easy to fabricate
- 100 percent recyclable



Advantages of copper-alloy net pens

- Stays naturally clean while maintaining maximum water exchange
- Reduced impact from pathogens and parasites, as monitored by farmers
- Reduces drag and maintains cage volume
- Reduces escapes from predation and storm damage
- Presents extended pen life and recyclability
- Provides low total cost of ownership




How much copper is lost due to corrosion?
How do CAM releases of copper compare to releases from current antifoulant-treated netting?
Laboratory and field measurements of copper releases due to normal corrosion

Major objective of copper-alloy mesh products: Reduce metal loss to extend working life with minimal maintenance

Cu

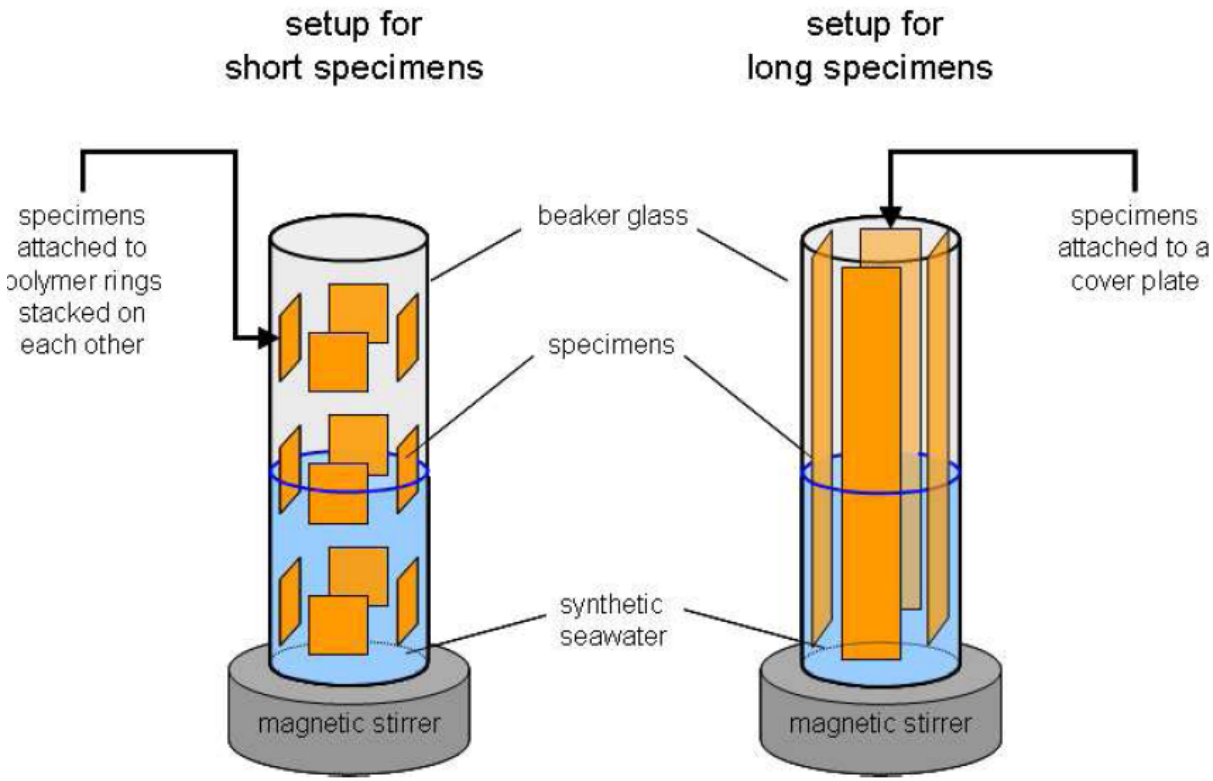
Corrosion sequence for copper alloys in seawater:

- Bare (“bright”) metal initially oxidizes with relatively soluble corrosion products (oxides, hydroxides)
- Over several weeks, relatively soluble corrosion products are replaced by less and less soluble salts: copper chlorides, copper carbonates
- These low-solubility corrosion salts form a protective patina on surfaces to inhibit further corrosion and metal loss

Copper releases to seawater during this corrosion sequence

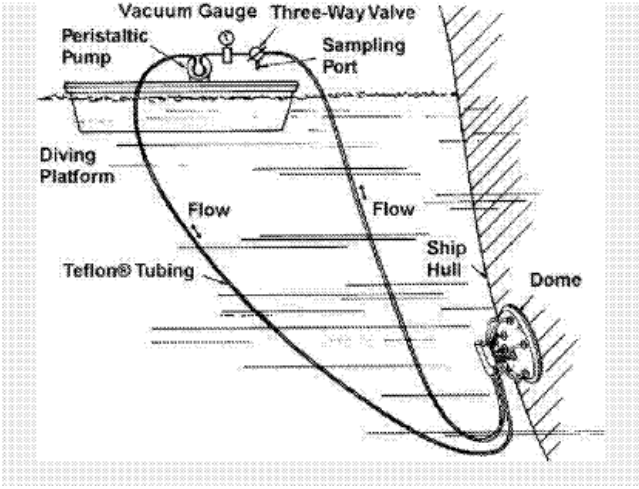
- Laboratory experiments: “Jar” tests (Major Testing Lab, Germany)
- Field measurements: “Dome” tests (U.S. Navy, San Diego)

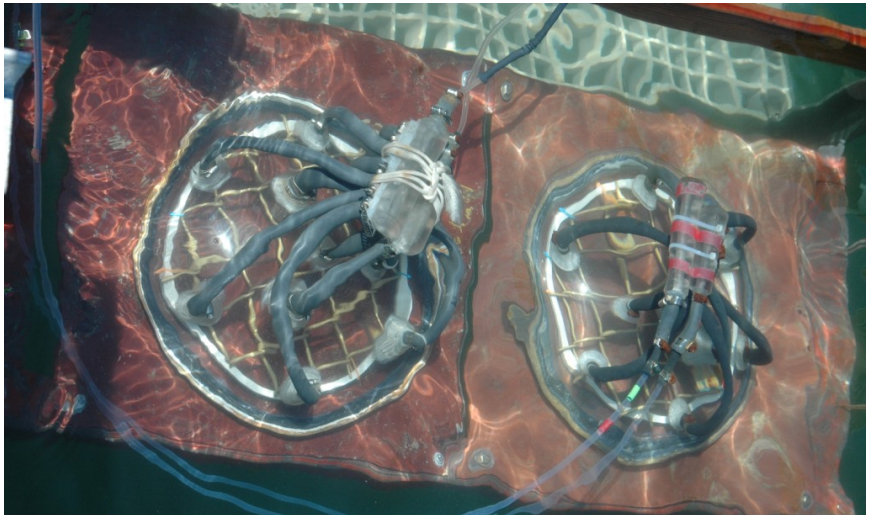
Laboratory corrosion tests (Germany)

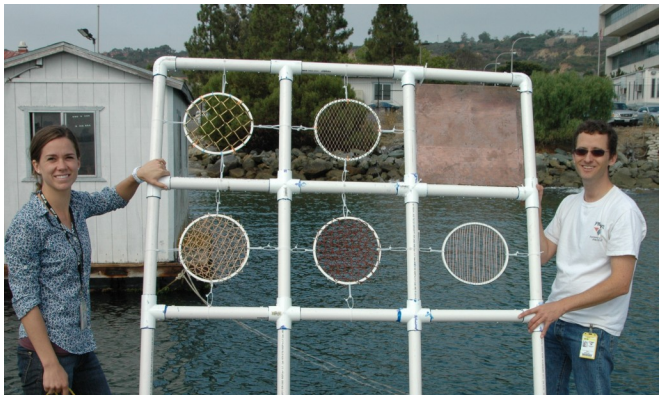


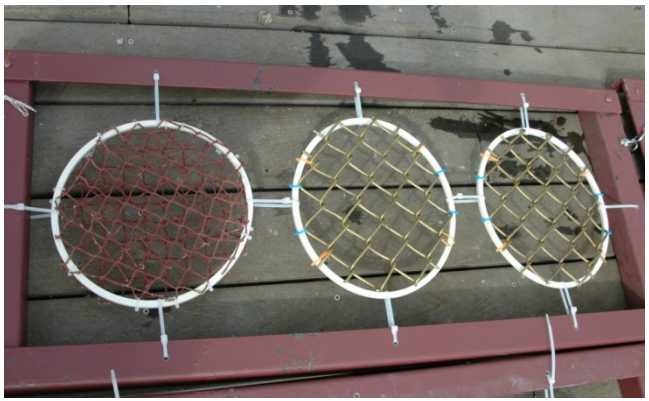
Schematic drawing of the two experimental setups

Field tests of copper release and toxicity (CA-U.S. Navy)

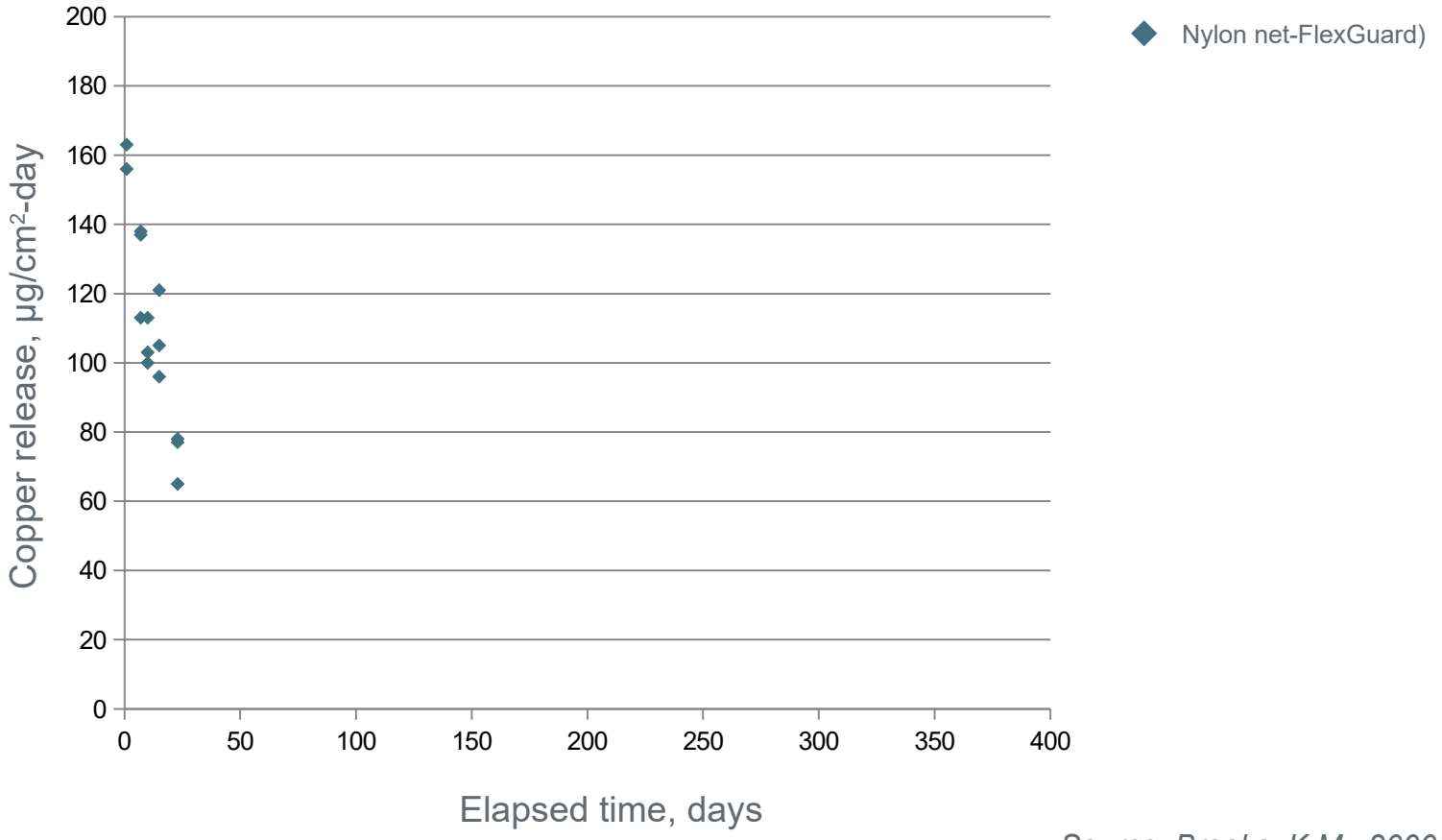






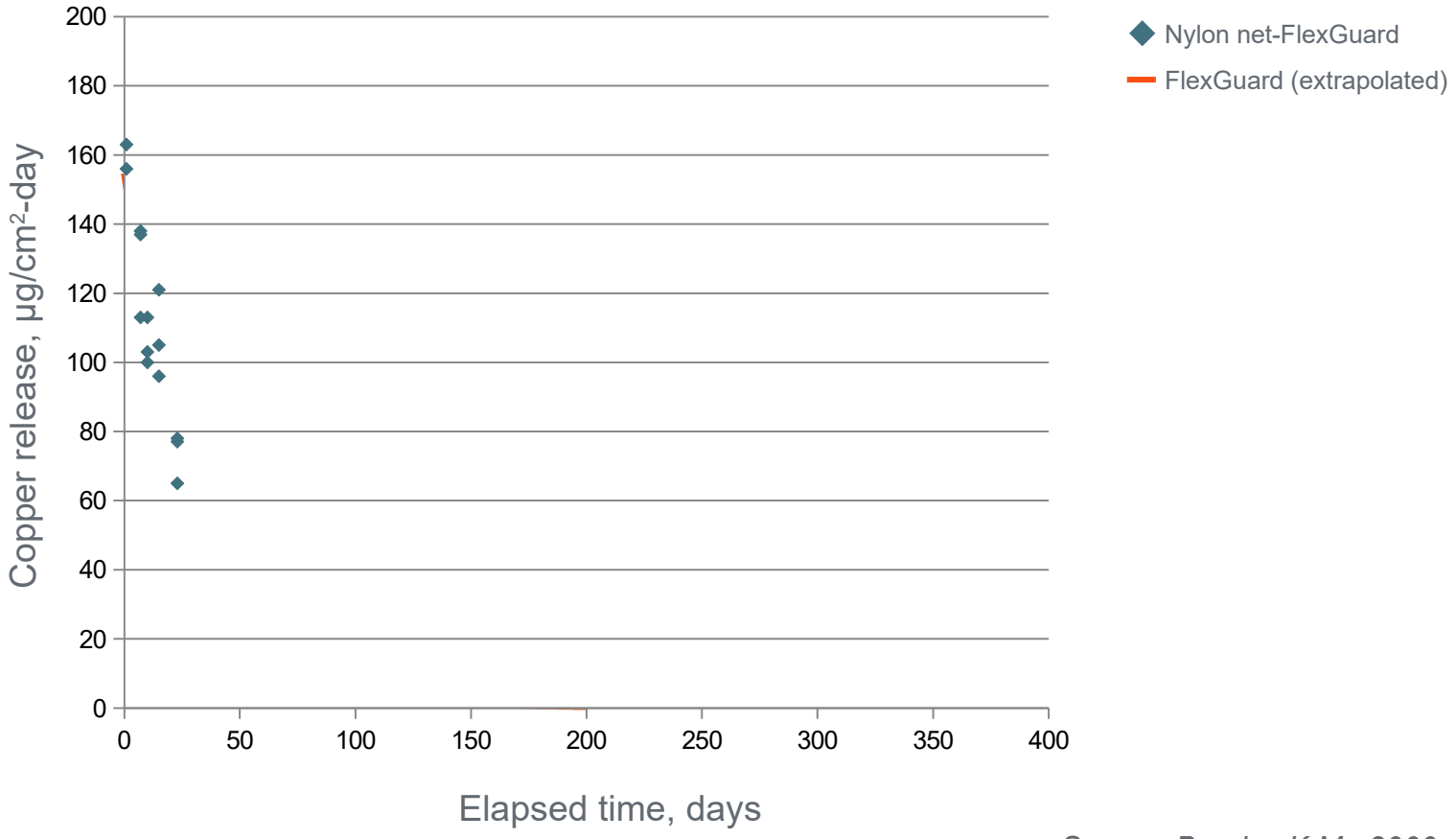


Copper release rates—current practice: Nylon mesh coated with antifoulant



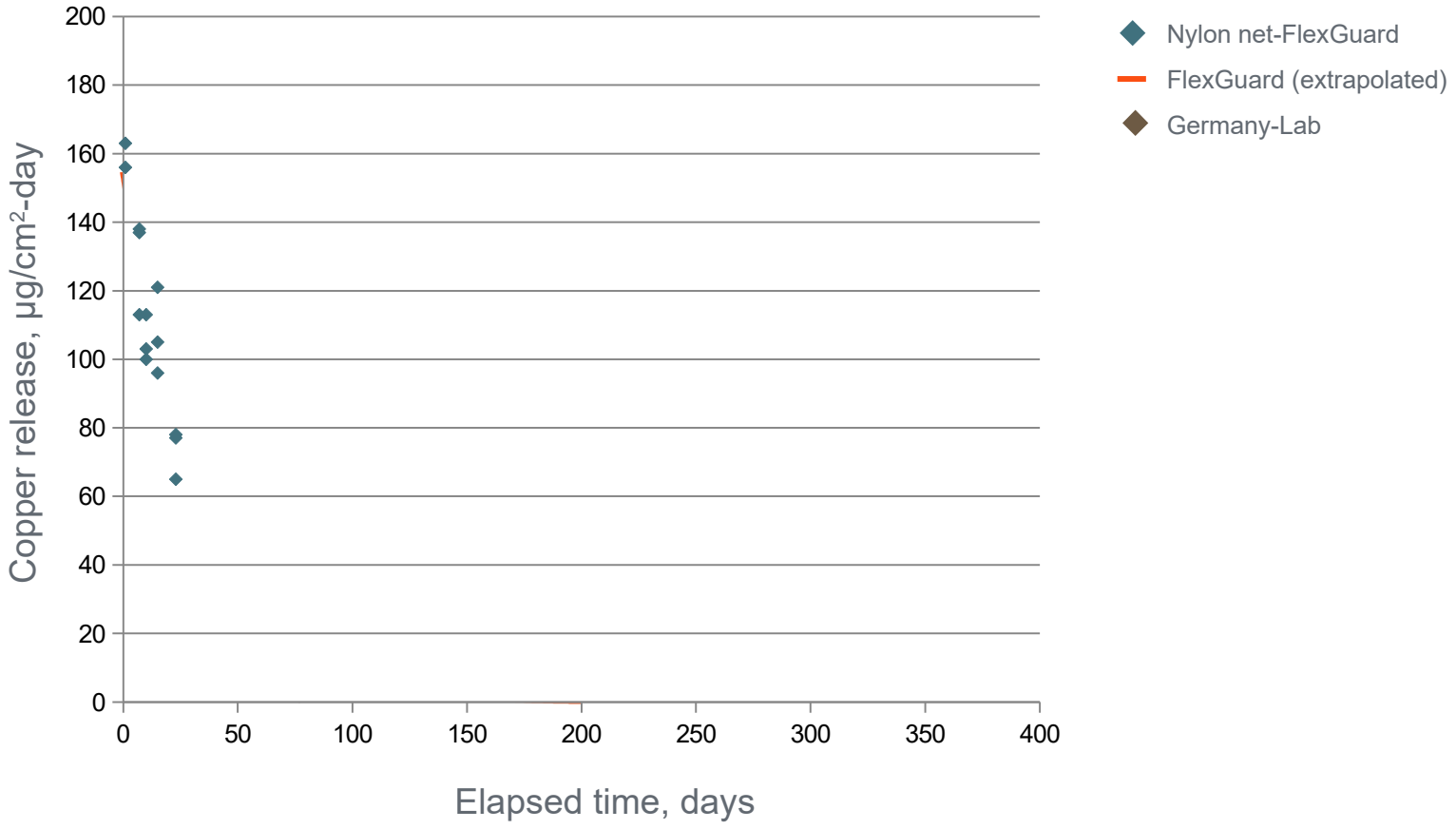
Source: Brooks, K.M., 2000

Copper release rates—current practice: Nylon mesh coated with antifoulant



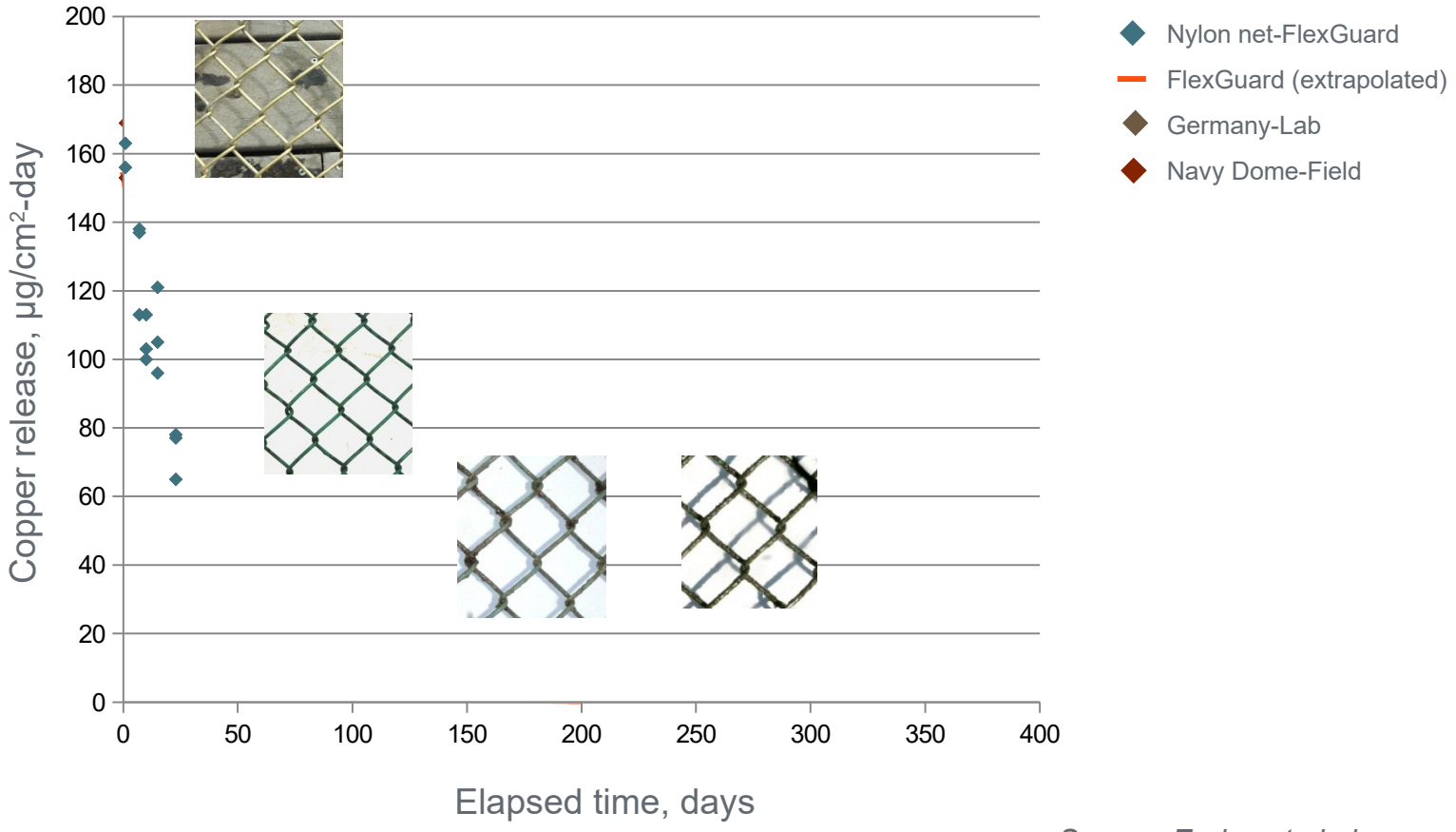
Source: Brooks, K.M., 2000

Copper release/corrosion rates—current practice vs. new copper alloy (brass) mesh



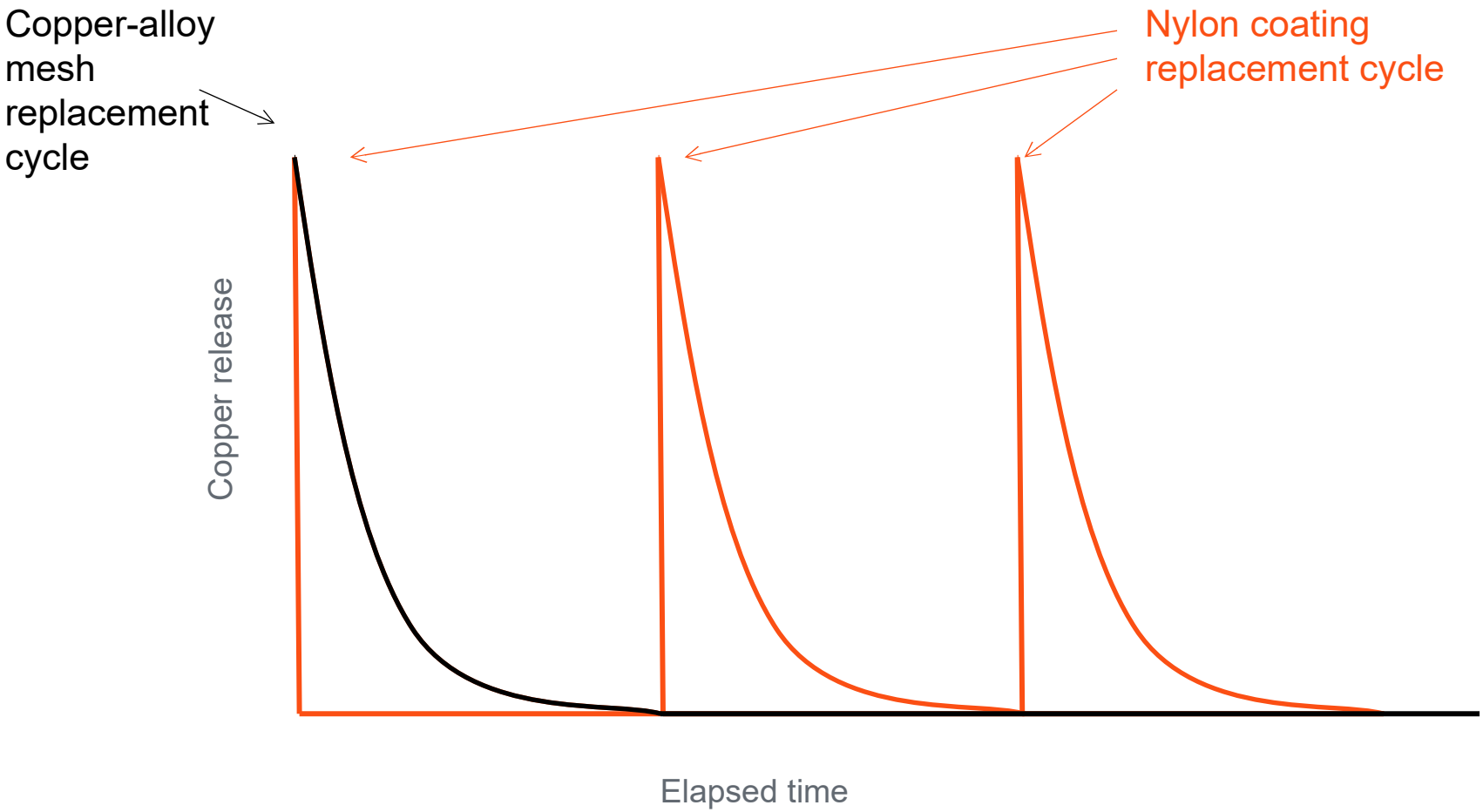
Source: Hofmann et al., in prep.

Copper release/corrosion rates—current practice vs. new copper alloy (brass) mesh



Source: Earley et al., in prep.

Comparative copper release rates from CAM and AF-coated nylon, over a typical grow-out cycle

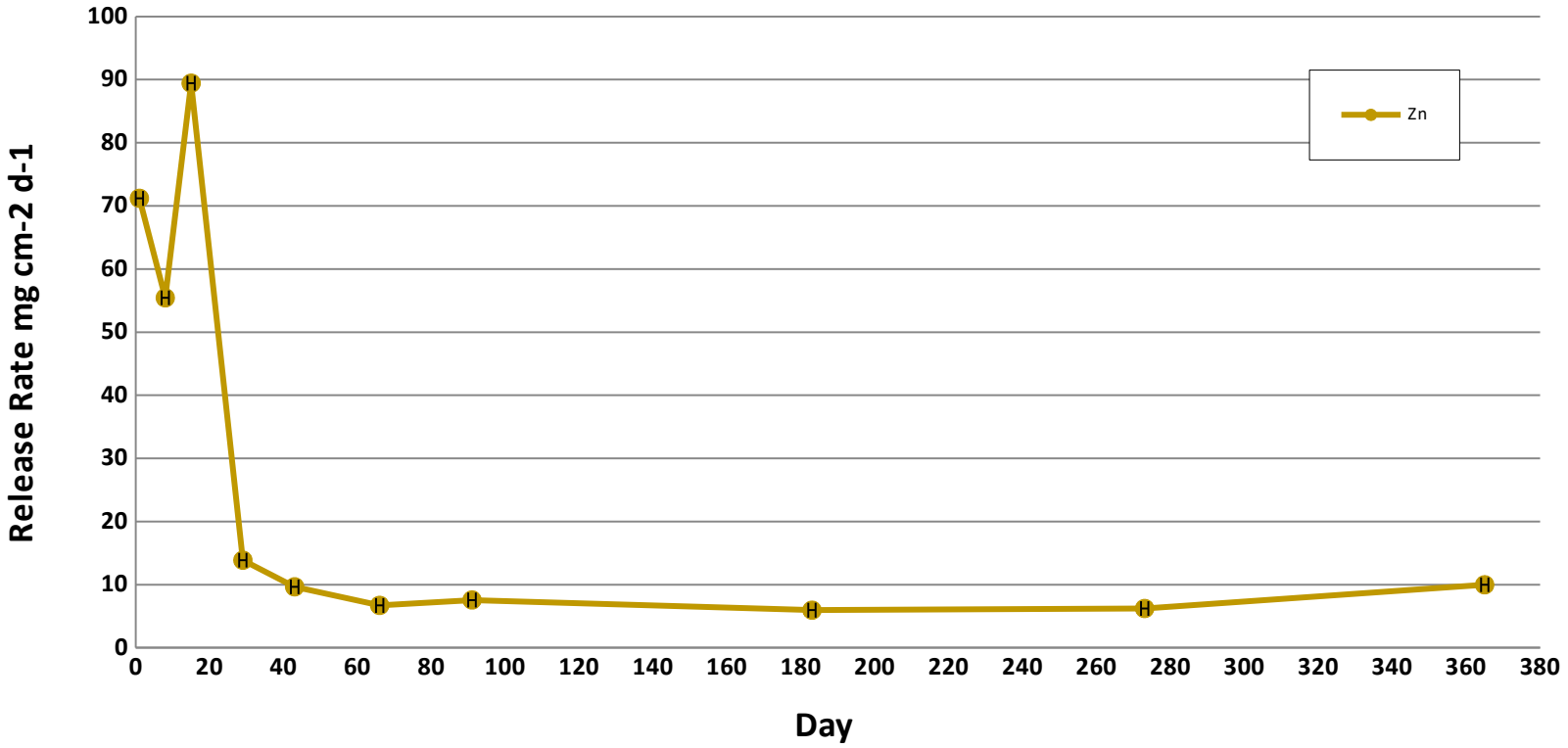


Release rate—conclusions

- Copper-alloy mesh release rates decrease rapidly as bright metal forms protective patina
- Total metal loss: < 2 percent over five- to eight-year lifetime in the water (based on initial pilot tests; agrees with extrapolation of these test data)
- CAM release rates over a grow-out cycle: much less than AF-treated nylon (where releases will “spike” every four – eight months when freshly-treated nylon net replaces copper-depleted and fouled net)

Zinc Releases from CAM Brass

Zinc Release Rates from 65:35 Brass Mesh



How much do copper concentrations increase in nearby waters?
Do copper concentrations near CAM pens comply with water quality standards?

Measured Nearfield Copper Concentrations at a Site in British Columbia, Canada

Sampling locations—British Columbia, Canada

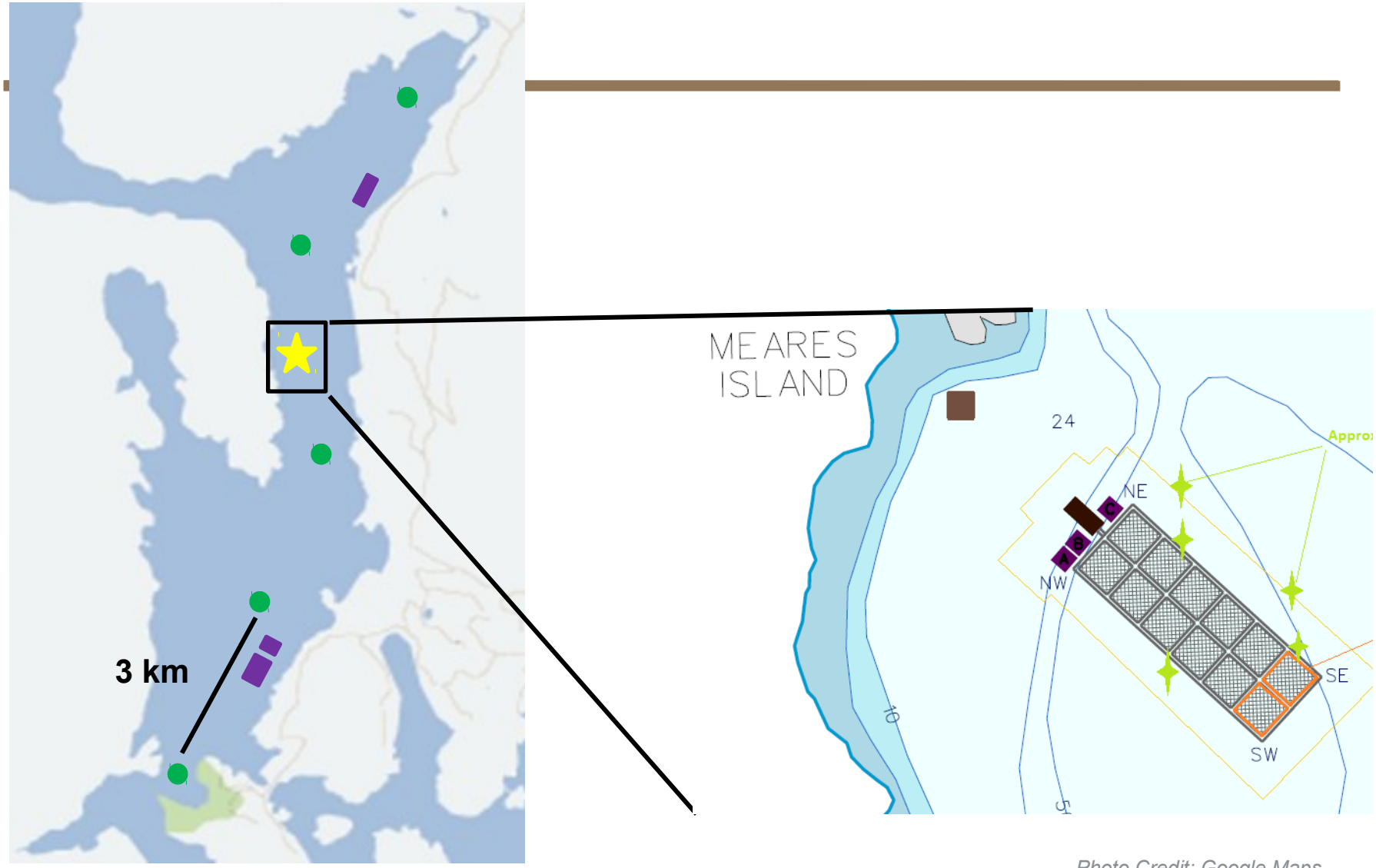
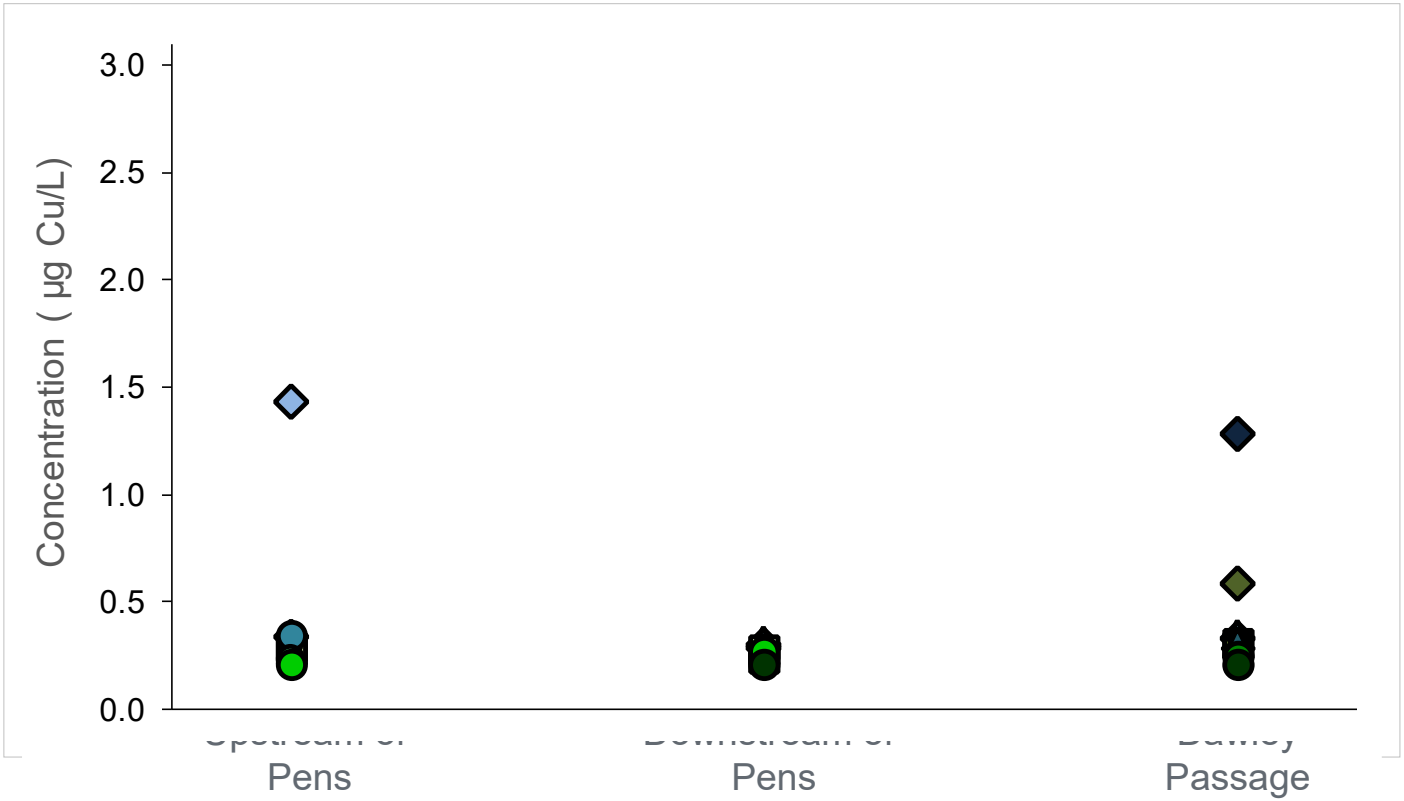


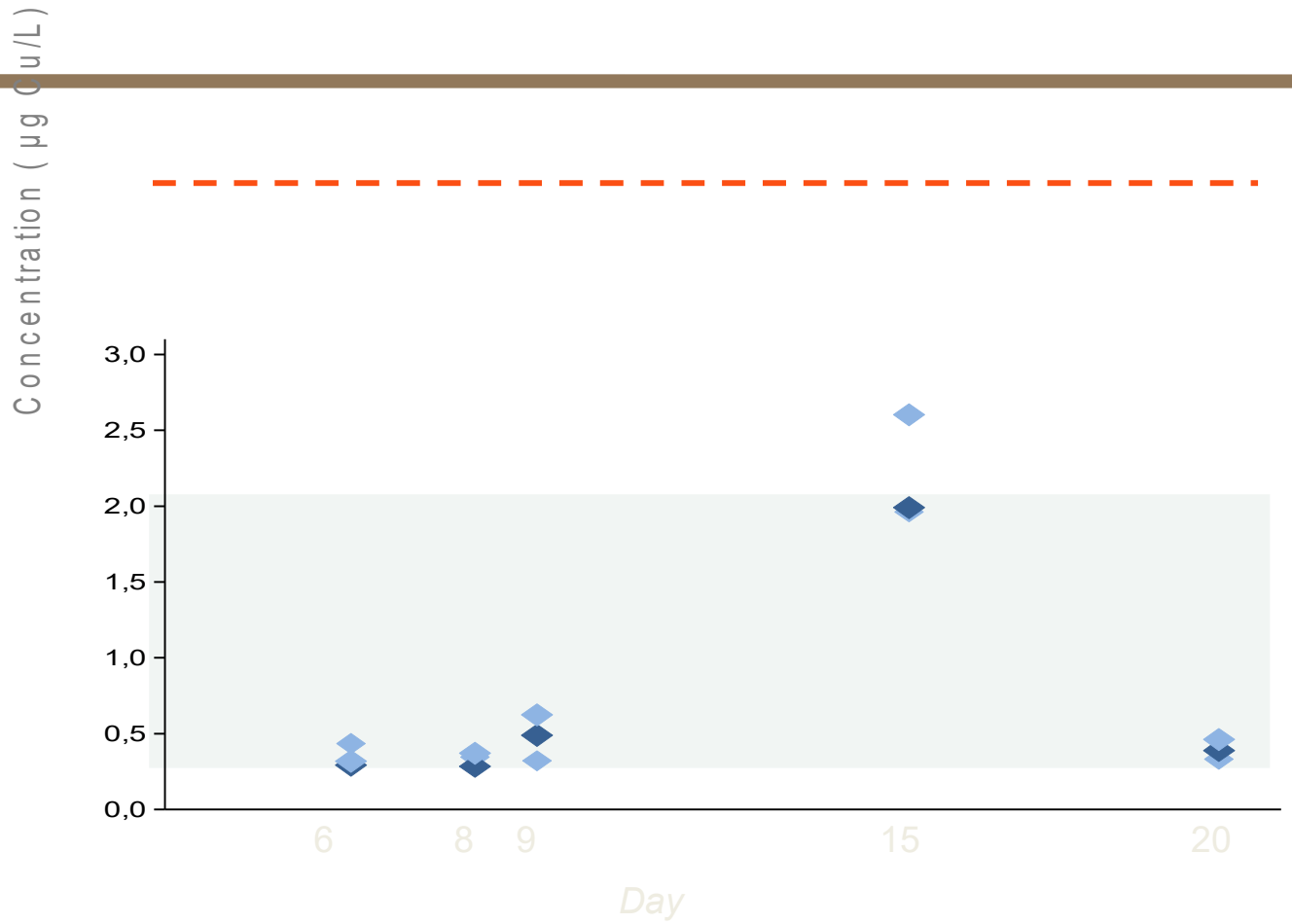
Photo Credit: Google Maps

Background Cu levels



Source: Smith et al., in prep.

Downstream samples over time



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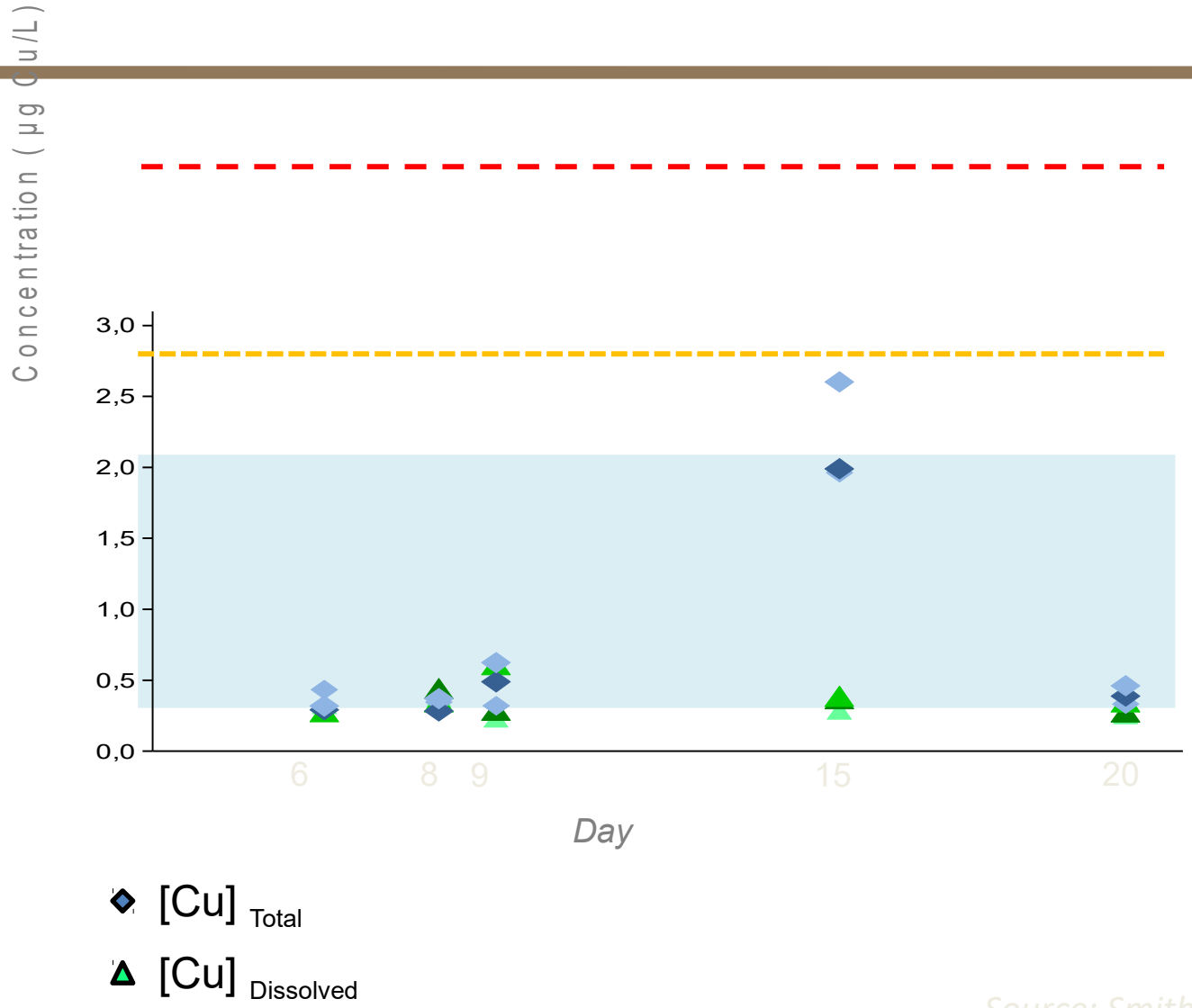


Source: Smith et al., in prep

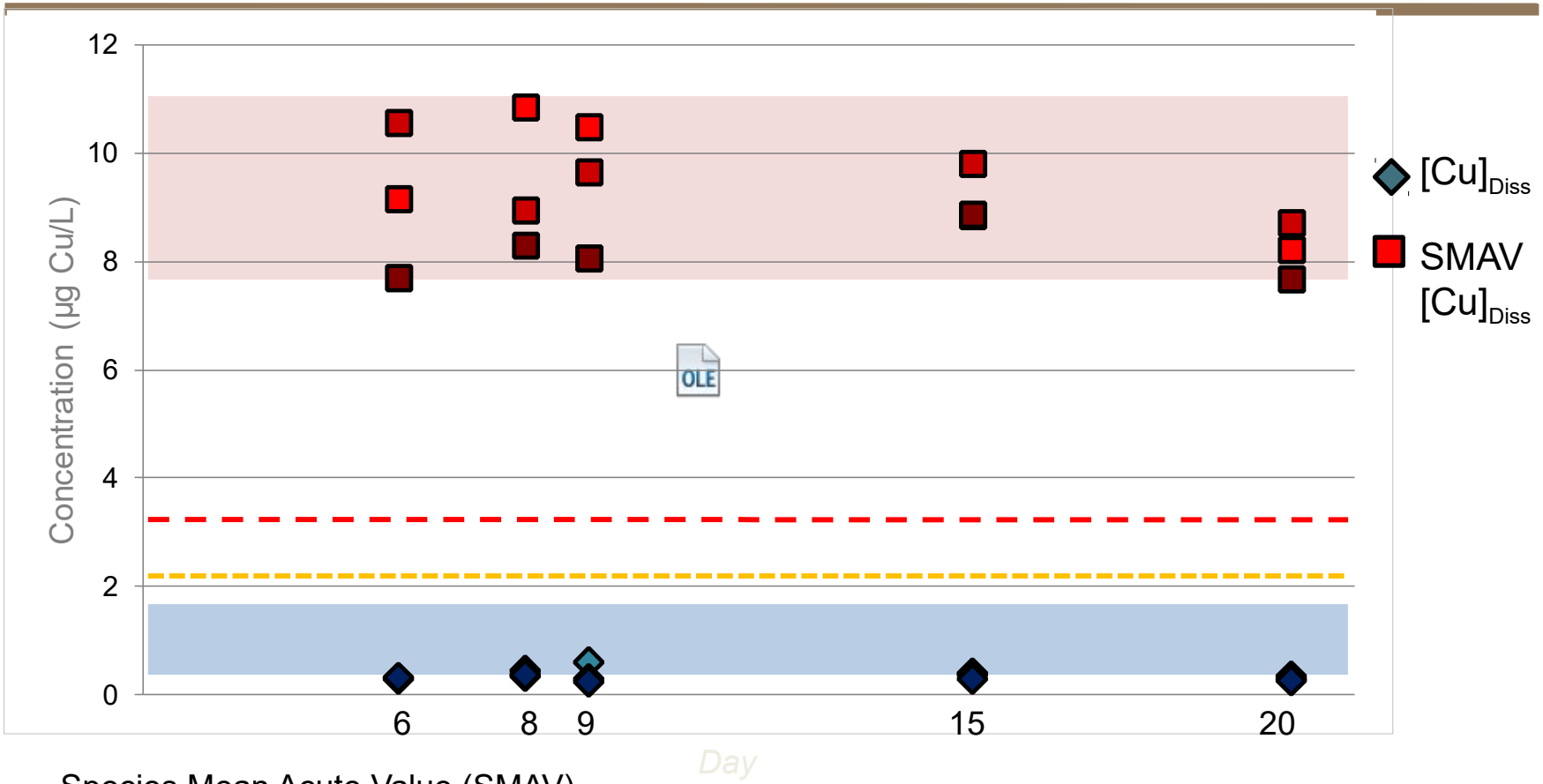
Conclusions

- Measured values are below applicable British Columbia water quality standards for copper.
- No consistent patterns to indicate detectable amounts of copper are being released from the newly-installed cages.

Is the released copper "bioavailable" to aquatic life in nearby waters?

Application of the Marine Copper Biotic Ligand Model to the British Columbia Data

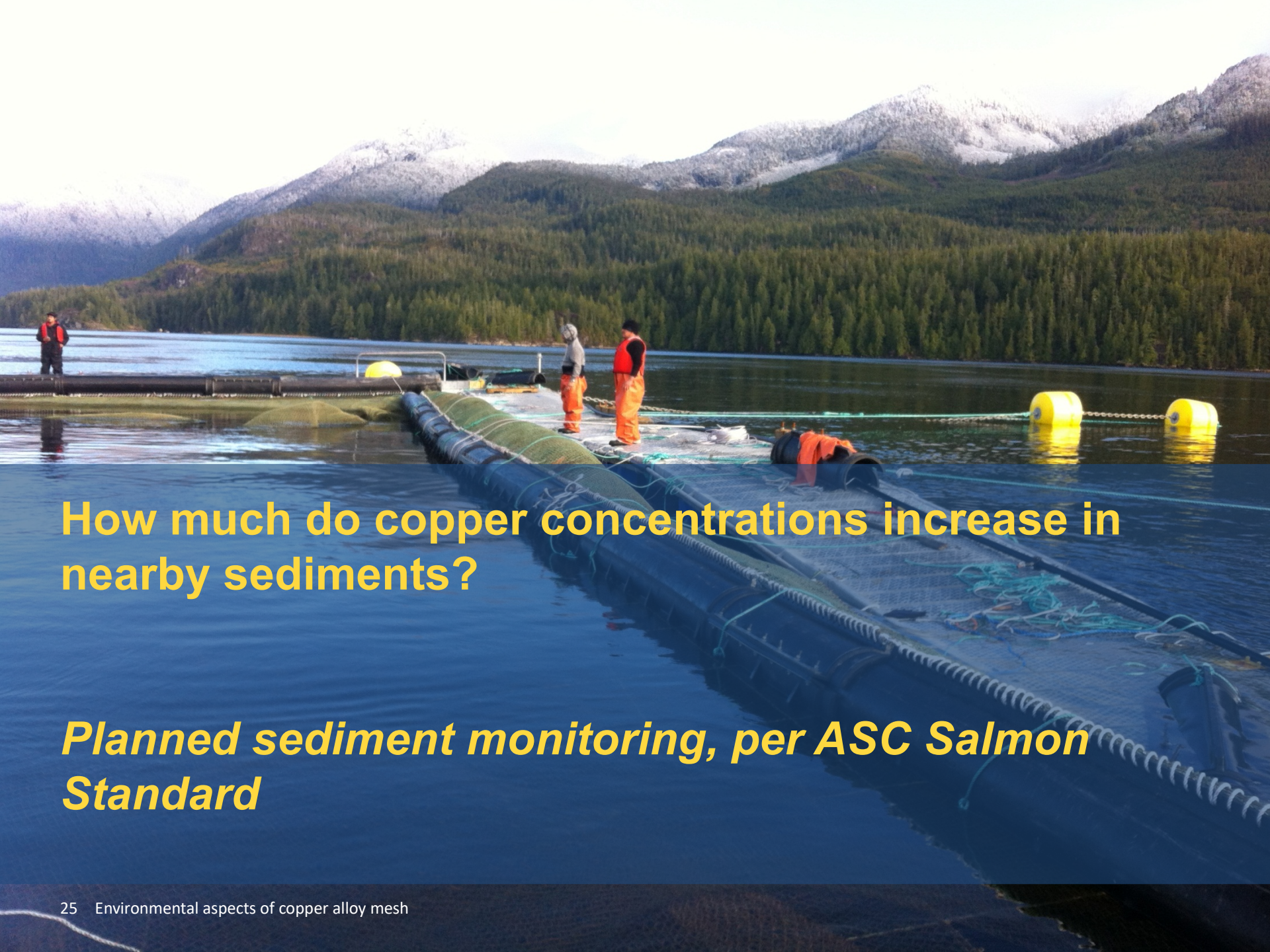
Downstream dissolved Cu concentrations



Species Mean Acute Value (SMAV)

- Average of EC50 data
- *Mytilus edulis*
  - Most sensitive organism in marine database

Source: Smith et al., in prep



How much do copper concentrations increase in nearby sediments?

Planned sediment monitoring, per ASC Salmon Standard

Copper Monitoring Requirements
(per Salmon Standard 1.0 of Aquaculture Stewardship Council)

Cu

From **Appendix I-1. Sampling methodology for calculation of faunal index, macrofaunal taxa, sulphide and redox, and copper:**

3. Three [stations] should be 25 meters outside the Allowable Zone of Effect (AZE), or 55 meters from the edge of the array of cages measured with a marked line and recorded using GPS. Of these, one should be upstream and one downstream with respect to the direction of the residual current, and the other should be to one side of the farm in a direction orthogonal to the residual current

4. [Duplicate samples] from [three]reference sites 500-1000 meters from the farm (edge of the array of cages), in similar water depth and substratum type (where this exists), and recorded using GPS.

Timing shall also be the same, sampling at peak cage biomass during the production cycle.

Sediment Sampling – Current Status

CAM Salmon Pilot Test Sites:

- **All salmon sites previously used copper-based antifouling coatings on polymer nets**
- **These sites have elevated and variable copper background, due to past or current deployment nearby of AF-coated pens**
- **Thus, these sites unsuitable for identifying discrete accumulation from CAM pens**

Sea Bass site in Vietnam:

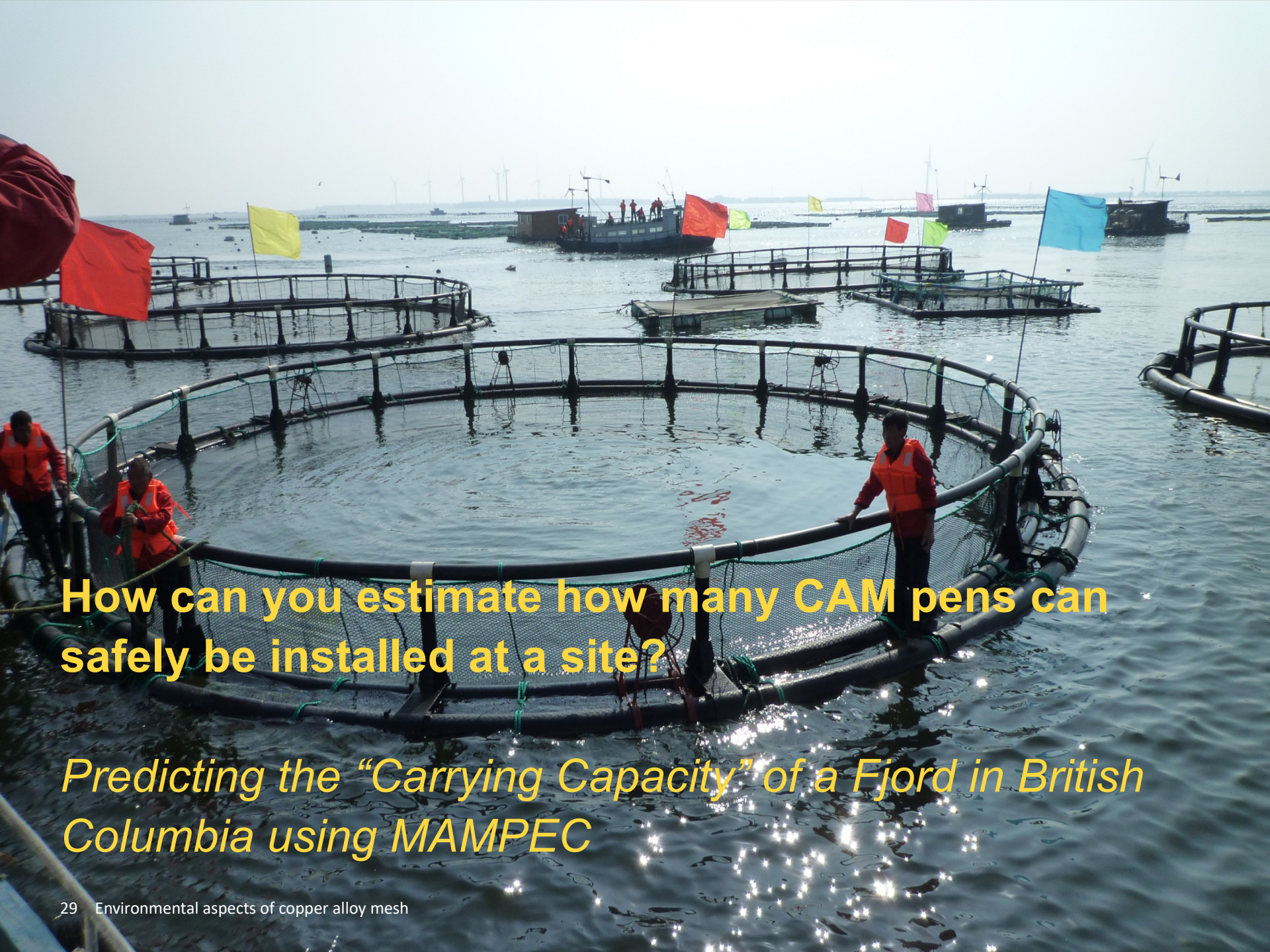
- **No copper antifoulants used in the past**
- **Full-life cycle 3 m x 3m x 3m pens deployed in April, 2014**
- **Sediment sampling planned**

Additional analyses to determine Bioavailable copper in sediments

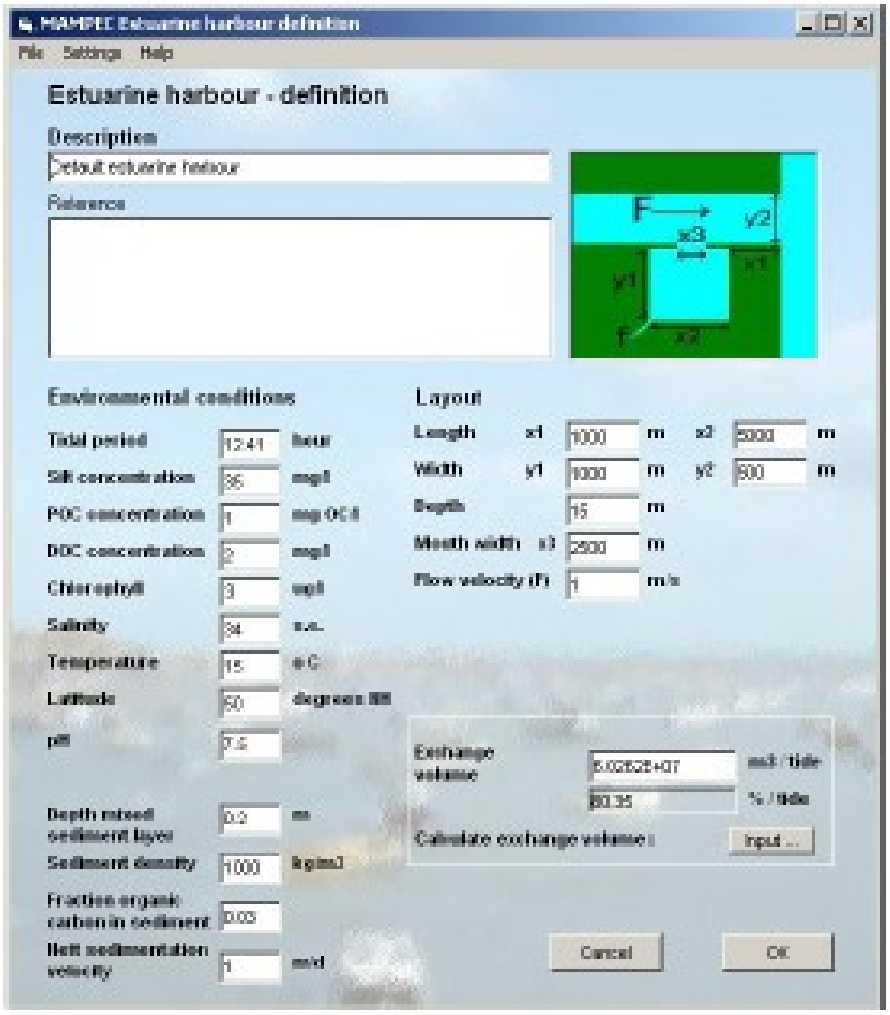
Cu

Sediments to be analyzed for:

- **Total copper**
- **Simultaneously Extracted Metals (SEM)**
- **Acid-Volatile Sulfide (AVS)**
- **Organic Carbon**
- **Concentrations in <63 um fraction (Simpson, S. et al. CSIRO 2009)**

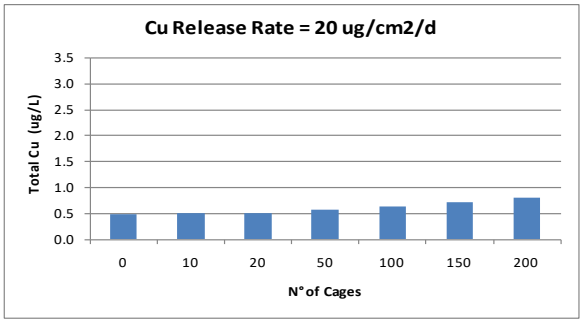

How can you estimate how many CAM pens can safely be installed at a site?
Predicting the “Carrying Capacity” of a Fjord in British Columbia using MAMPEC

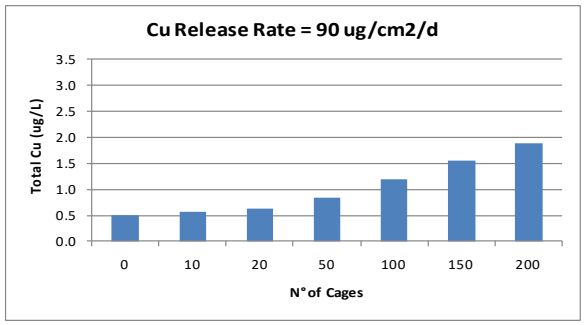
Extrapolation of conservative release rate estimates to real pen deployments: MAMPEC

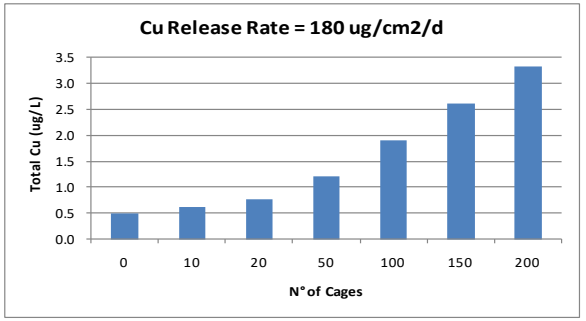


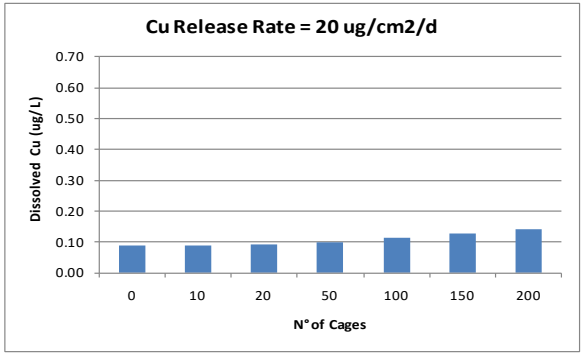
MAMPEC predictions for closed BC fjord

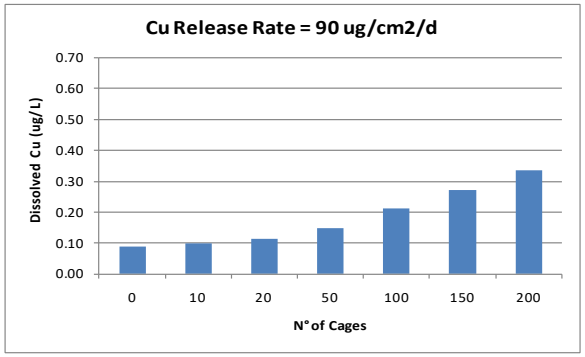
Cu

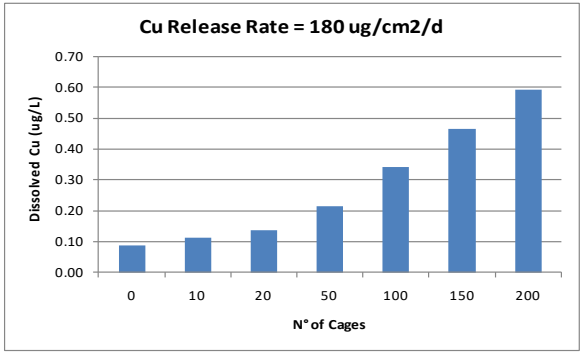


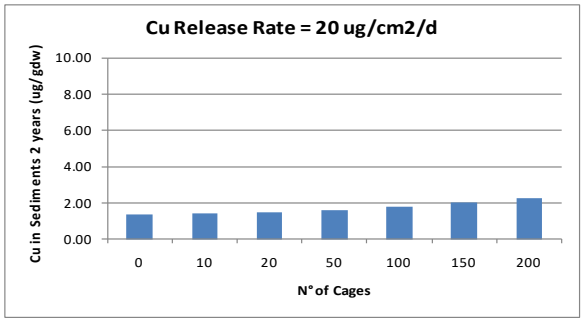


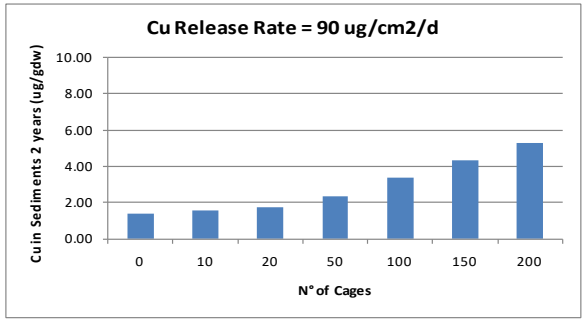


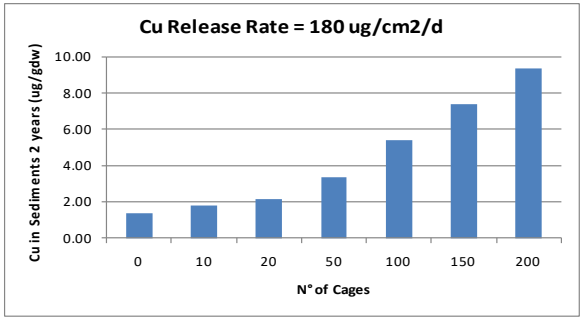












Conclusion: Releases of copper to the aquatic environment from CAM corrosion

- Even with 200 pens deployed in small bay, predicted increase in total copper likely < 0.5 μg/L.
- Bioavailable fraction (basis for regulatory standards in U.S. and EU) much lower still.
- Therefore, no likelihood of exceedance of marine environmental quality standards for copper.

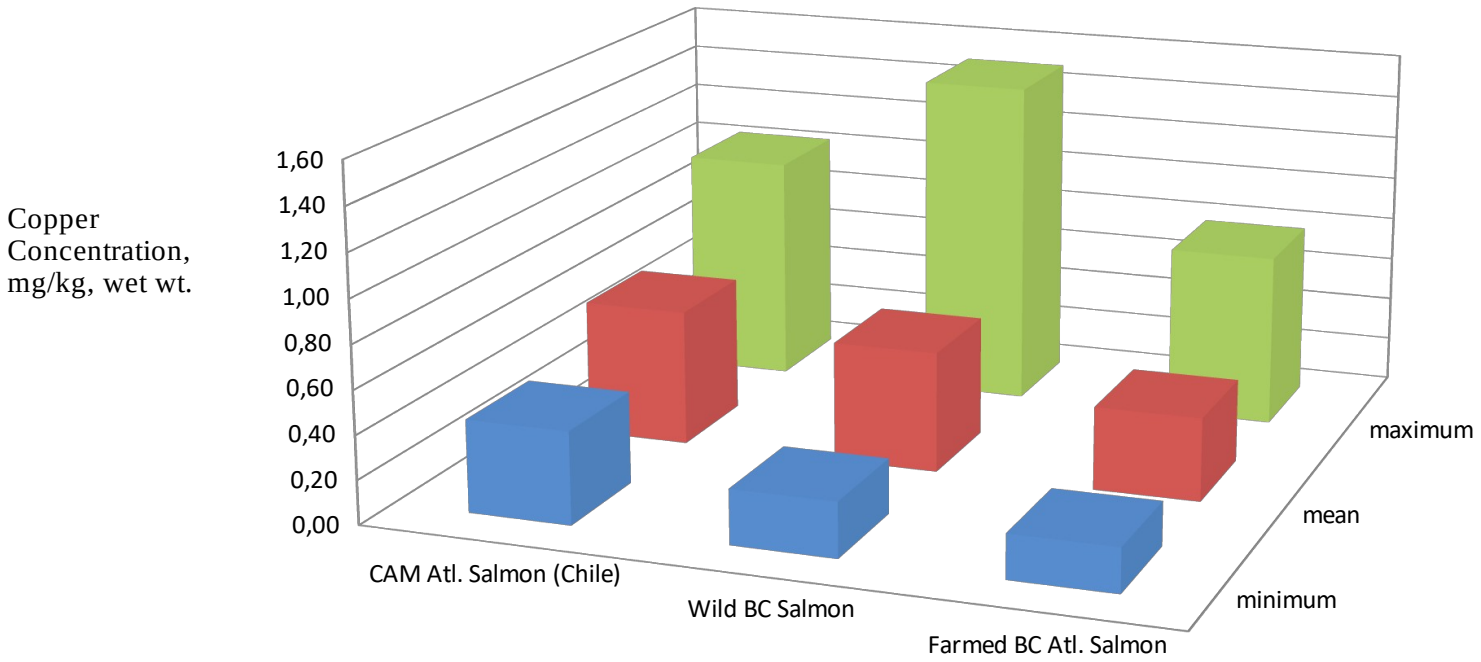
Source: Torres et al., in prep.

Does the copper accumulate in the tissue of the fillets headed to market?
How do copper levels in CAM-farmed fish compare to conventional pen-farmed salmon, or wild-caught salmon?

Tissue measurements in CAM-farmed Salmon

Copper concentrations in salmon fillets

Cu



Sources: EcoSea, in prep. (Chilean salmon)
Kelly, B.C. et al., 2008 (BC wild and farmed salmon)

Conclusion: No food safety issues

Copper concentrations in fillets of Atlantic Salmon harvested from **copper-alloy mesh** pens are no different from copper concentrations in :

- Wild-caught Pacific salmon
- Atlantic salmon raised in conventional nylon pens (with copper AntiFouling coatings)

Summary

Economics, growth performance and disease

- Lower incidents of disease
- Lower operating costs
- Less environmental impact

Environmental effects and food safety

- Reduced copper releases relevant to current coated nylon technology
- Copper levels in fish tissue—equivalent to wild caught salmon

Thank You!

For more information please contact:

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Or visit:

CuAquaculture.org

Cu Copper Alliance