Technical Information

ASC certification and environmental performance of copper alloy mesh

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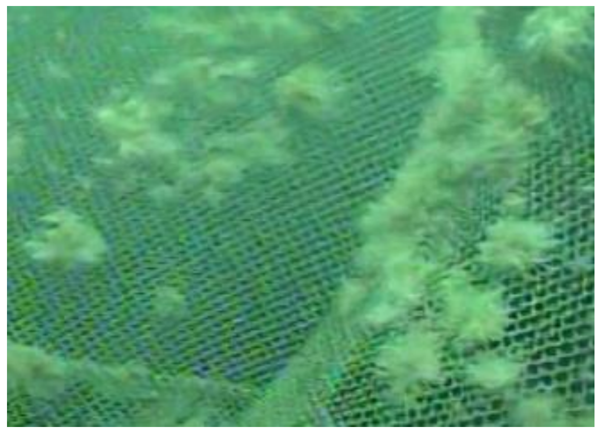

March 2016 v3 – for meetings in Japan – H. Stillman

Introduction

This paper provides a technical overview of how a fish farm raising salmon in copper alloy mesh (CAM) aquaculture cages can achieve Aquaculture Stewardship Council (ASC) certification. It also provides guidance for achieving this certification at farms where a CAM cage system will be installed, and provides an explanation of how CAM performs in the marine environment.

This document was prepared by the International Copper Association based on more than 10 years of international experience with government regulators, leading scientific researchers, fish farmers, and non-government organizations.

The interested reader is directed to the references provided to gain deeper scientific information.

Background

The rapidly increasing density and diversity of aquaculture production facilities has been accompanied by a variety of unintended and undesirable adverse effects, drawing the attention of numerous stakeholders. Regulators, fish farmers, and customers have become more aware of environmental effects, food quality, and animal welfare. There are many elements of environmental performance in aquaculture.

There are four main reasons to use copper alloy mesh materials in net pen containment:

1. To prevent biofouling and associated maintenance
2. To improve fish health and welfare
3. To reduce the risks of enclosure failure and fish escape
4. To reduce life cycle environmental impacts

The consequence of these four factors is that fish farmers can reduce their operational and maintenance costs, reduce the risks of loss of fish or infrastructure, and improve environmental performance. It is for all these reasons that the use of copper alloy mesh materials in net pen containment systems is growing.

Aquaculture Stewardship Council certification requirements

The Aquaculture Stewardship Council (ASC) has developed detailed performance standards for salmon farms, and standards are being developed for six other farmed species. The ASC's Salmon Standard v1.0 establishes seven detailed operational and other Criteria for individual farms applying for ASC Certification for their products. It does not certify specific components such as moorings, feeders, cages or nets. Only fish that have been produced in ASC-Certified farms have the right to use the ASC logo. Therefore, if any given farm complies with the all seven Criteria during the inspection procedure, that farm will obtain the ASC Certification for its fish products.

The ASC Salmon Standard (v 1.0) relevant to copper requires only that the accumulation of copper in sediments beneath a cage does not exceed 34 mg/ kg, as total copper. The ASC has the same requirements for a cage with a copper alloy mesh or a copper treated net. The standard for the copper release to the environment are the same in both cases.

In the case of metal cages, the ASC Standard indicates in Sub-Criteria 4.7.3: "For farms that use copper nets or copper-treated nets, evidence of testing for copper level in the sediment outside of the Allowable Zone of Effect (AZE), following methodology in Appendix I-1". Further, the ASC is currently using a copper concentration benchmark in sediments of 34 mg/ kg, as total copper. This sediment concentration is based on a worldwide lower threshold for toxicity to benthic organisms. However, this value is lower than natural background concentrations in many areas, and is unrealistic for use in many areas.

The ASC staff, including the Director of Standards Development, recently have indicated that they would be amenable to a tiered approach, such as used in Australia/New Zealand, in which the ASC benchmark of 34 mg/kg (dry weight), would become a first-tier trigger or screening value. If exceeded at a farm, the applicant would move on to a second tier, in which the "bioavailable" fraction of copper is estimated in local sediments, and used to estimate the potential for toxicity to the sediment organisms near the pen(s). This tiered approach may be incorporated in the next version of the ASC Salmon Standard, and in Standards for other species.

Sediment sampling

The ICA is sampling sediments, and measuring metal fractions and other parameters that determine the fraction of copper that is bioavailable to benthic organisms, at CAM test sites in Norway and Japan. The ASC Standard only requires sampling of copper at the time of maximum biomass (i.e., near harvest). However, this harvest-only sampling would, in effect, attribute all of the measured copper in nearby sediments to releases from the pen, ignoring natural background, and contributions from nearby treated nylon pens, moored boats, and other anthropogenic sources. To correct for this, ICA's protocol is to collect both pre-installation and maximum biomass samples of sediments.

Accordingly, initial samples were collected in Norway and Japan at the locations where test pens would be installed and evaluated. Additional samples are planned to be collected when the pens are moved from these evaluation sites to the grow-out sites. The results of the first sampling in Hitra, Norway (prior to pen installation) indicated a Total copper concentration in the sediment of 7 to 12 mg/kg (except for one outlier sample). This is less than one-third of the current ASC Benchmark for Total copper; further, the extractable (bioavailable) concentrations were 1% or less of the Total concentrations.

Background concentrations of copper, and any increases in copper concentrations that have occurred while the pens were moored at the structural evaluation sites, will provide an indication of compliance with the current ASC Benchmark value of 34 mg/kg. Based on the initial sampling date, we believe it will not be necessary to further assess the fraction of this total that is bioavailable, and thus potentially toxic, to sediment organisms. (As a second tier, in anticipation of the ASC's adding bioavailable copper to its next version of its Salmon Standard)

<u>Based on the low initial value of copper in the sediments, the slow release of copper ions from the copper alloy mesh, and the natural dispersion of the copper ions due to currents, we are confident that there will not be an issue with increased copper concentration in the sediments at the time of harvest.</u>

In summary, the sediment sampling plan for the pen in Norway is as follows:

1. Sample sediments at structural evaluation site at time of installation and determine total copper content (completed May 2015)

2. After 11 months, sample sediments at same site to determine if there is any change in copper value (planned for March 2016)
3. Sample sediments at farm installation site just prior to moving the cage to this site (planned for April 2016)
4. Sample sediments at harvest (planned for October 2016)

Detailed sampling requirements

The ASC Standard Appendix I-1 describes the sampling methodology for calculation of faunal index, macrofaunal taxa, sulphide and redox, and copper

Grab sampling for the faunal index, macrofaunal taxa measurements, and sulphide and redox should be conducted at nine stations in duplicate during peak cage biomass for the production cycle.

1. Two stations should be from the cage edge, one at each end of the long axis of the farm

2. Three should be from within the Allowable Zone of Effect (AZE), 25 meters from the edge of the array of cages at slack tide measured with a marked line and recorded using GPS. Of these three, 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

3. Three should be 25 meters outside the 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. One from a reference site 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

5. For farm sites using a site-specific AZE, sampling locations shall be determined based on that AZE, at distances consistent from the boundary of the AZE as for other farms (e.g., five meters inside of AZE and 25 meters outside of the AZE, recorded using GPS, and in multiple directions as determined appropriate through the modeling

For farms using copper-based nets or copper-treated nets, copper sampling shall be conducted at the same locations outside the AZE as the other benthic sampling, at three stations outside the AZE, in duplicate. The reference site used shall also be the same, and two additional reference sites are needed. Timing shall also be the same, sampling at peak cage biomass during the production cycle.

Release of the cupric ion (Cu++) prevents biofouling

Biofouling impedes the flow of clean, oxygenated water to the fish being cultured, provides a growth environment for parasites and pathogens that can infect fish. The removal, cleaning, and disposal of biofouled nets requires care to avoid adverse impacts. Biofouling also increases the drag forces and structural loading on aquaculture systems and requires stronger structures and mooring systems to prevent catastrophic failure.

Fig. 1 Four months after deployment in the North Atlantic in June 2009, the plastic structure of this net pen (right) is heavily fouled while the copper alloy mesh remains free of fouling. Source: University of New Hampshire.

Typical polymer nets can become biofouled within weeks. Fish farmers must change polymer nets frequently, clean the nets in situ, or use antifouling coatings to maintain water flow. Typically, even antifouling-coated nets must be cleaned or replaced every four to eight months (Bravo et al., 2003). As fish farms move offshore into cleaner water with more energetic sea conditions, avoiding biofouling becomes critically important for structural integrity and for worker safety.

Marine organisms attach themselves to some materials more readily than they do to others. Steels, titanium, aluminum, and high density polyethylene will foul readily. Copper-based alloys have very high inherent resistance to biofouling. This is particularly so for macrofouling (seaweeds and shell fish) although microfouling (microbial slimes) will still occur albeit to a reduced extent. When exposed to long time periods under quiescent conditions, some macrofouling can eventually occur on copper alloys, but this has been observed to slough away at intervals and can readily be removed by a light wiping action.

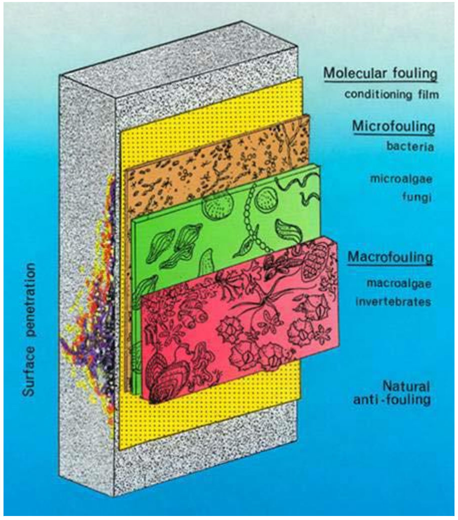

Figure 2: Development of fouling on marine structures proceeds in a sequence from a slime layer, to microfouling (bacteria, microalgae, fungi) to macrofouling (macroalgae, invertebrates); from NERC News, 1995)

Copper's biofouling resistance is achieved by the slow release (corrosion) of copper ions from the surface of the copper alloy materials. In seawater, metallic copper oxidizes to cuprous oxide (Cu_2O); this dissociates to release the cuprous ion (Cu^+) into a very thin surface boundary layer above the metal surface. Further away from the surface, this ion further oxidizes to the cupric ion (Cu^{++}), which is mainly responsible for the effect that prevents the growth and adhesion of biofouling organisms.

Because corroding copper will release trace amounts of copper, it is reasonable to assess the effects and ultimate fate of this released copper.

Release of the cupric ion (Cu++) has minimal effect on the marine environment

Copper is an essential element required for normal growth in all plants and animals and is a normal constituent of the ecosystem. Figure 3 below shows a typical dose-response curve for micronutrients such as copper, indicating the range of concentrations across deficiency, adequacy, and toxicity. Marine organisms, including all types of fouling and fish, obtain the copper they need from copper in water, food, and in sediments. Eliminating fouling on net pens requires a toxic concentration of free copper (the Cu^+ and some Cu^{++} ions) in the stagnant boundary layer next to the mesh surface. But the concentration of Cu^{++} ions bioavailable to fish must not be in the toxic range.

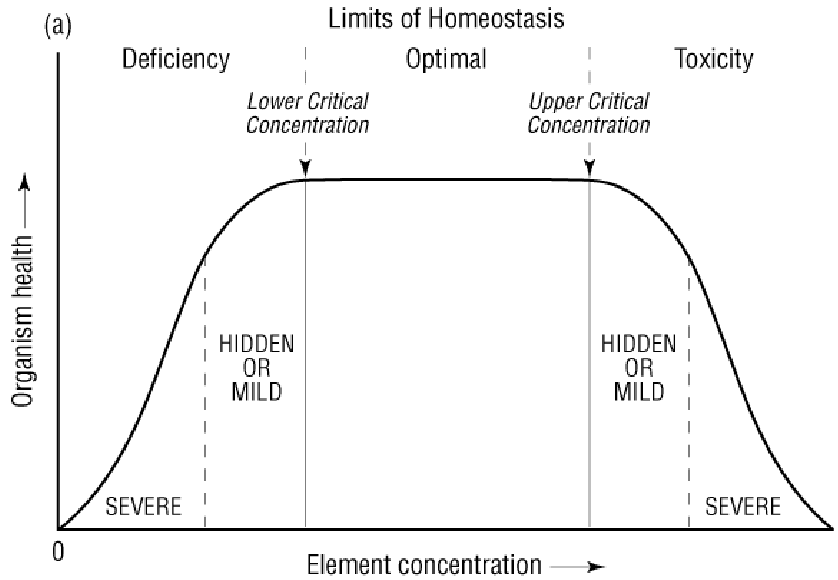

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Figure 3: Cupric ion concentration on the surface of copper alloys in seawater is in the toxic range while the concentration of bioavailable copper inside net pens is at the normal background level in the optimal range.

In a study performed by SINTEF (Norway) in 2005, the total concentration of copper in the immediate vicinity of net pens was calculated for various current velocities and mesh materials. The results show that the expected concentrations are in the range of or below measured background concentrations at current velocities above 10 mm/second, which is a minimum current velocity at aquaculture locations in Norway. According to this SINTEF study of copper alloys, “the toxic concentration causing the actual antifouling effect will only be experienced on the surface or in very close vicinity on the individual wires to the net.”

Numerous studies have shown that the most of the copper present in marine environment is not present as the cupric ion. Most of the dissolved copper is complexed with organic and particulate material in marine and freshwater environments. This reduces or completely removes its ability to be taken up by organisms (i.e. its bioavailability) and therefore toxicity to marine organisms. The Biotic Ligand Model describes the fate of copper ions in the marine environments. This model is the basis for the marine PNEC for copper approved by the European Commission, and is being adopted by regulators worldwide to accurately predict how local water quality conditions bind up most of the cupric ion, greatly reducing its bioavailability, and thus the potential for toxicity.

The key point is that cupric ions released from copper surfaces are rapidly dispersed by local turbulence and ocean currents, and rapidly bind to natural organic matter (NOM) in the seawater. Therefore, the copper released is generally not bioavailable or toxic.

Further, the ASC recognizes the universal effectiveness of this process, and thus to not specify any sampling for copper in waters near the pen, or further afield.

Copper in the marine environment

Copper occurs naturally on Earth and in seawater. The concentration is about 50 ppm in the Earth’s crust, about 1 ppb in coastal seawater, about 0.25 ppb in the open ocean, and to over 100 ppm in sediments. Copper concentrations can vary significantly in seawater mainly due to natural discharges from rivers and hydrothermal vents. Because of the natural ubiquitous availability of copper, life evolved to make use of this copper as an essential micronutrient. Further, all organisms have evolved sophisticated mechanisms to cope with varying environmental copper levels taken up from their surrounding environments. For instance, algae in the open oceans actively scavenge copper from seawater to meet minimum requirements, while healthy fish can excrete any ingested copper that exceeds their metabolic needs. In salmon, the normal level of copper in salmon muscle is around 2.0 micrograms/gram dry weight.

Studies (including Peterson, L. K., “Copper levels in the muscle and liver tissues of farmed Chinook Salmon”) have shown that these fish were not bio-accumulating copper from antifouling coatings on the net pens or from copper alloy mesh. This is attributed to the dispersion of copper ions into seawater, the rapid complexation of cupric ions, and the natural homeostasis and detoxification processes.

The anti-biofouling effect is limited to organisms that are in contact with the copper material surface (i.e., experience the higher concentrations of cuprous and cupric ions in the stagnant water layer next to the surface). This is consistent with the observation that copper surfaces in the air environment exhibit a surface killing effect on microorganisms. The mechanism of action of surface killing is unique and is in the process of being elucidated by researchers. Evidence of this surface effect is seen on adjacent steel and copper nickel surfaces in seawater where biofouling on the steel stops abruptly at the edges of the copper nickel.

The behavior of solid copper materials differs from copper-based antifouling coating applied to nylon nets. Traditional nets are composed of woven polymer filaments. Coatings include minute cuprous oxide particles in a binder. The coating is impregnated into the spaces between filaments and adhered to the net filaments. The bonding between the coating and the net is weak as compared to a solid copper surface. The surface area of a coating composed of particles on filaments is much greater than the surface area of a smooth solid surface. During handling and use, polymer nets are subject to movements and flexing, and are exposed to corrosive seawater. As a result, small flakes and particles of the coating can be released into the water, and due to their weight, will settle on the sea bottom in the vicinity of the net pen. Further, the coating in normal use on the netting can release more copper than metal alloys. Since the release of cupric ions is proportional to surface area exposed to seawater, the release rate of cupric ions is higher for coated nets than for solid copper mesh. This is why coated nets lose their antifouling capacity after a period of months while solid copper mesh has permanent antifouling performance. In addition, solid copper alloy does not contain binder materials that are not normally found in seawater and may have unknown effects.

The ASC is concerned about copper in sediments around cages

Concern by ASC about the effect of copper in sediments in the vicinity of fish farms is primarily based on the use of antifouling coatings and their effect on the benthic environment. Deposition directly beneath the enclosure of cuprous oxide particles and ions from antifouling coatings results from the binding of released ionic copper directly to local particulate organic matter (both of natural origin and from feces and uneaten feed), which sinks to the benthic environment. There, the copper can further bind to sulfides in Redox-negative (“black-colored”) sediments. The NOM-bound and sulfide-bound copper is not bioavailable to benthic organisms, but, small amounts of unbound excess copper may be bioavailable. Thus, some organisms that inhabit sediments may be subjected to a toxic level of copper. The use of solid copper mesh reduces the potential for this sediment deposition and local benthic toxicity because the cupric ions are dispersed rapidly in seawater and little of the copper reaches the benthic environment in a bioavailable form. However, the ASC is concerned about long-term buildup in the sediments, and subsequent adverse effects on benthic organisms, so they have specified sampling of copper and some associated chemicals in the sediments.

In summary, copper ions released from copper alloy mesh in aquaculture systems:

- Do not have effects on non-target organisms– the growth of fouling organisms is prevented in a target zone limited to the surface of the copper alloy mesh, while natural processes reduce the bioavailability of copper beyond this zone
- Do not create copper concentrations in the marine environment detectable above the natural background level– copper is complexed with organic materials present in seawater, dispersed by natural currents and tides, and is deposited in sediments
- Do not build up in the marine food chain– organisms at every trophic level have mechanisms to excrete excess copper, so it cannot bioaccumulate in tissues or magnify up the food web.

Nonetheless, it is useful to understand the copper ion release rate for copper materials that are used in marine aquaculture. Cupric ions are released through the processes of corrosion. All materials have low general corrosion rates up to moderate sea water flow rates. All rely on the formation of a protective surface film to form naturally by exposure to sea water to provide their basic corrosion resistance. For copper alloys immersed in sea water, the general corrosion rate is usually less than 0.02mm/yr, decreasing with time as the protective surface films mature. This corresponds to a metal loss of no more than 1 to 3 % over the first salmon grow-out cycle.

Figure 4: Copper alloy chain link mesh used in aquaculture shown immediately upon retrieval from 15 meter depth after 4 months of immersion. The invertebrates are moving on the surface. Note the complete absence of biofouling and the greenish corrosion protection layer that forms naturally upon exposure to seawater.

Corrosion, and release of copper to the environment, from copper alloy mesh

The corrosion performance for the copper alloy material to be used on cages in Japan is excellent. The average corrosion rate for UR30 material as measured in 2 and 5 year exposure trials in sea water is 0.005 mm/year.

SINTEF performed an analysis of copper release from UR30, a standard 65% Cu-Zn brass, and nylon nets coated with copper-based antifoulant. All net pens were 20 x 20 x 10 meters deep. The actual measured average corrosion rate for a UR30 brass net is 0.005 mm/year. The study estimated the amount of copper released based on an average corrosion rate of 0.03 mm/year from 2.5 mm diameter wire. This is 6 times greater than the actual corrosion rate. Even at this rate, SINTEF concluded that "the amount of copper released from a solid metal mesh net is no greater than the release from a traditional nylon net coated twice per year." As shown in Figure 5, the actual amount of copper released from a solid metal UR30 net is substantially less than the copper released from a nylon net coated with copper-based antifoulant.

Release to surroundings, 20 years (total)	**Nylon net cage** 25 mm with copper antifouling coating; 80% release	**UR 30, 25 mm** 0.03mm/year average corrosion rate	**UR 30, 25mm** 0.005mm/year average corrosion rate
Copper (kg)	2673	1931	321

Figure 5: Release to surroundings during 20 years assuming 80% of copper in the anti-fouling paint is released when the nylon net cage is in the sea (SINTEF, 2005).

Copper release rates from surface corrosion of copper plumbing tube have been studied intensively. The same type of test rigs used to confirm the acceptable copper release rates from copper tube in drinking water systems can be applied to measure copper release from copper alloy mesh in seawater.

This testing was performed at Wieland's laboratory in 2011 (Wieland, 2011).

Strips of 65:35 Cu:Zn, as well as eight other alloys, were immersed in beakers with stirred artificial seawater (Fig. 6). The water was changed periodically, and metal concentrations were measured.

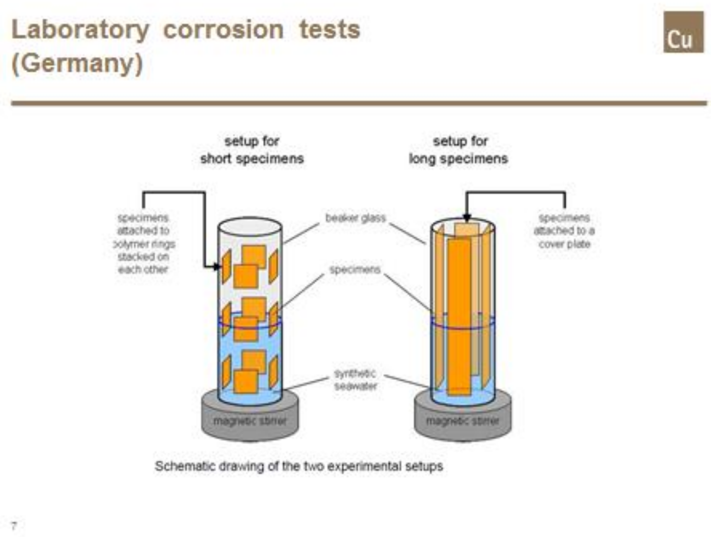

Figure 6: Test setup for measuring corrosion rate of copper samples in artificial seawater at Wieland Werke's laboratory. The experiment continued for 105 days, and copper release rates (□g Cu/cm^2-day) are plotted in Fig. 7:

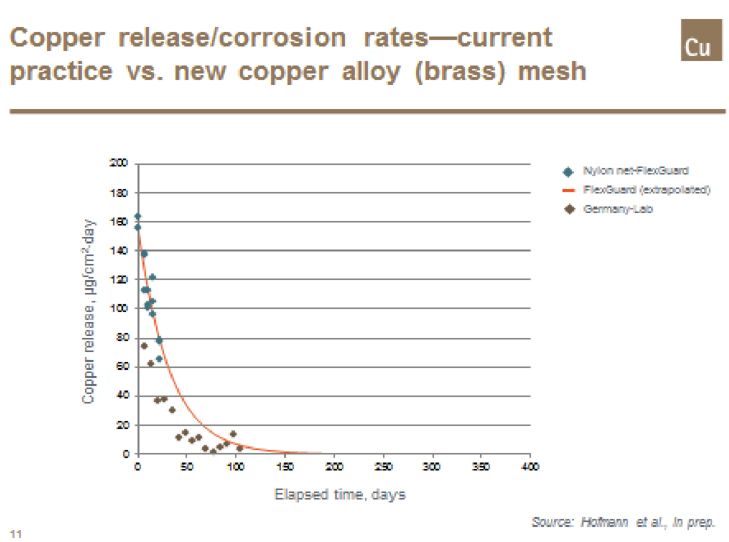

Fig. 7: Release rate of copper from 64:35 brass (µg Cu/cm^2-day; brown diamonds; copper release rate from nylon net treated with Flexguard (cuprous oxide-based antifoulant): measured data (blue diamonds); extrapolated curve (orange line).

The release data show a high initial release rate as the bright metal oxidizes and the surface oxide readily dissociates. The release rate decreases over time as the surface oxides are replaced by less-soluble chlorides and carbonates.

The copper industry sponsored field research to confirm Wieland's lab-measured release rate. The US Navy's SPAWAR lab developed realistic test protocol to provide data on the copper ion release rates of copper and other substances from surfaces coated with antifouling paints (e.g., ship hulls), as measured in micrograms per square cm per day, at specific time intervals.

The SPAWAR lab and ICA adapted the method to measure copper releases from mesh samples in the field. Samples of brass mesh, and other copper alloy meshes, were deployed on racks below floats in San Diego Bay for a full year. Periodically, a dome was sealed over each sample, and the buildup of copper in the water was measured, and used to estimate release rates (see Fig. 8 for a photo of the Domes during a test, and racks holding samples for the 64:35 mesh; see Finnie, 2006, for a further description of the Dome Method).

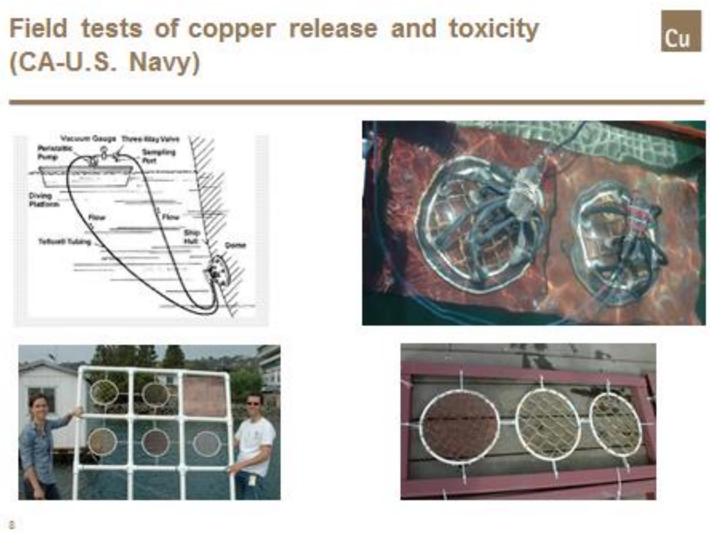

Fig. 8: Dome Method apparatus, and samples of various copper alloy meshes.

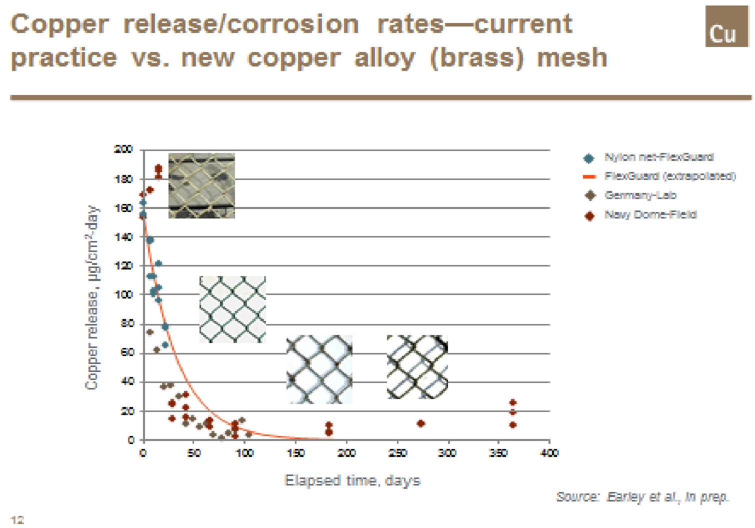

Fig. 9: Data from Figure 7, with added data on the release rate of copper from 64:35 brass (μg Cu/cm^2-day; copper-colored diamonds).

The field data in Figure 9 show a release rate pattern similar to Wieland's lab data – an initial transient of high release rates (up to 180 μg/cm^2-day), which quickly (within 3 or 4 weeks) declines to a steady state in the range of 20 to as low as 5 μg/cm^2-day). Further, both field and the lab data on the copper alloy mesh show releases less than measured (and extrapolated) data from cuprous oxide antifoulant-coated polymer nets.

Copper concentrations in water near pens with copper alloy mesh

The lab and field-measured release rates do not directly provide estimates of resulting copper concentrations in ambient waters around copper alloy meshes. During the deployment of two pens with copper alloy meshes at a salmon aquaculture site in British Columbia, Canada, total and dissolved copper concentrations were sampled as near as 1 meter off the meshes, as well as at background locations before, during and after the deployment of the two pens. Copper concentrations were determined using inductively coupled plasma mass spectrometry (ICP-MS) and anodic stripping voltammetry (ASV), with detection limits of 0.1 µg/L or lower. For all samples measured, the average of total Cu was 0.89 µg/L with a 95% confidence interval of 0.22 µg/L, a maximum value of 3.30 µg/L and a minimum value of 0.17 µg/L. For water samples, there are some small spikes in total Cu that occurred during and after pen installation, but these spikes generally did not correspond to spikes in the dissolved copper fraction (associated with toxicity). After installation, total copper returned to concentrations observed prior to the beginning of pen installation activity. The results indicate that all sample values were below copper marine water quality standards for British Columbia, and even further below bioavailability-based thresholds predicted by the marine Biotic Ligand Model (BLM) (and allowed as alternate site-specific standards[1] to the Province's Criteria based on total copper). Most importantly, there were no consistent patterns to indicate that significant amounts of copper were being released from the newly-installed pens.

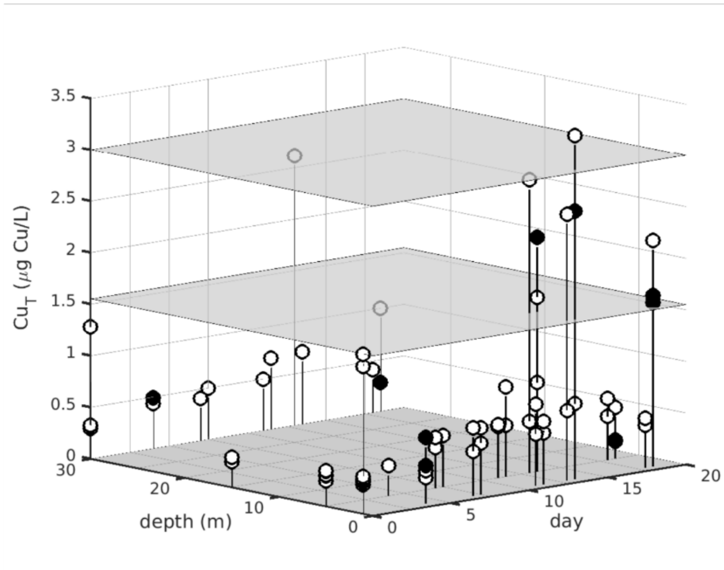

Fig. 10: Total copper concentrations measured for samples at various depths and times bracketing the installation of copper alloy nets at Plover Point. Open circles correspond to ICP-MS analysis and filled circles correspond to ASV analysis. Background samples are included as day zero; these background samples range as high as 1.5 μg/ (middle plane through data). The subsequent days correspond to the dates during and immediately after completion of the pen installation process in November and December 2012. The upper plane is the BC Maximum Standard.

Based on ICA's extensive experience with laboratory and field studies of the release rate from copper alloy mesh products, we expect that the concentration of copper in the water around copper alloy net pens to always be within the range of natural background ambient copper concentrations.

Life cycle analysis of copper alloy mesh aquaculture cages

When comparing one material to another, an accurate assessment of the life cycle impacts of the materials in the field is complex and contentious. Nonetheless, ICA and our partners EarthShift Global have managed to publish a peer-reviewed article in the premier Industry journal **Aquaculture** describing the life cycle performance of copper alloy mesh as compared to nylon mesh with antifouling coating (Ayer et al., 2016).

The LCA article highlights a range of operating conditions conducive to the use of copper-based mesh and also reveals previously unquantified environmental benefits of using copper mesh throughout the aquaculture supply chain. Nylon mesh used in net-pen aquaculture systems is prone to fouling by marine organisms, requires regular cleaning and has a relatively short service life. In contrast, the properties of copper alloy mesh and its more rigid structure have the potential to lead to an improved culture environment. Specific benefits of copper alloy mesh

[1] From the British Columbia water quality standard for copper: "***2. when detailed knowledge on the bioavailable forms of copper is available, the form of copper in the criteria for aquatic life can be modified, as justified by the data"***

include reduced predatory interactions, reduced fish escapes, reduced maintenance and net replacement and less waste due to the recyclability of the copper-mesh materials. Improvements in operating performance, achieved by using copper alloy mesh can result in improved water circulation and dissolved oxygen levels, reduced crowding and stress on fish, improved fish health and reduced feed inputs.

Grow-out trials featuring the culture of Atlantic salmon (Salmo salar) in copper-alloy net pen systems were conducted in Chile between 2010 and 2012. The salmon farmer collected data on operating inputs and outputs, fish growth, infrastructure inputs, and transport of salmon feed within the supply chain. These data were compared with industry-average net pen operating performance in Chile for 2012. The trial showed a few operating performance improvements with the copper alloy nets, including a 10% reduction in feed use, 15% reduction in on-site energy use, 79% reduction in labor hours and 31% reduction in antibiotic application.

See: http://www.cuaquaculture.org/aquaculture-profiles/aquaculture-insights-a-life-cycle-assessment-of-the-environmental-performance-of-copper-mesh/

A more sustainable aquaculture technology

We are confident that copper alloy cage technology provides improved conditions for farming Salmo salar and Seriola and do not anticipate issues regarding ASC certification.