International Copper Association, Ltd.

Frequently Asked Questions—Copper Alloys in Aquaculture
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This document introduces the nonspecialist reader to the use of copper alloys in aquaculture. If further analysis is required, the references cited throughout this document offer a deeper understanding of the subject matter.

Aquaculture Activity

1. *What is aquaculture?*

   Aquaculture is a group of technological activities directed at culturing or farming aquatic species, covering the complete or partial life cycles and carried out in selected and controlled environments, be it natural or artificial water environments, both in marine as well as in fresh and brackish waters. The health and growth of the species are actively managed during the farming process to improve production and profitability. Aquaculture supplies almost half of the world's demand for fish.

2. *What percent of global production occurs in marine, fresh and estuarine or brackish environments?*

   Globally, aquaculture is carried out in three different environments: 1) freshwater, with 59.9 percent of world production; 2) marine production, with 32.3 percent; and 3) brackish water, with approximately 13.3 percent (*FAO Statistics*, 2010). The greatest amount of growth is projected for the marine environment.

3. *What farming technologies are used to farm fish in marine environments?*

   Fish, mollusks, and crustaceans represent the main resources cultured in marine environments. Fish are preferably cultured in cage-net systems using a flexible net grid (synthetic fiber grid), where they are confined in a pen constructed of semi-rigid or rigid (galvanized steel, copper alloys) nets. Cages may be classified as: a) flexible and fixed cages, b) rigid and fixed cages, and c) rigid and submersible cages[1]. The latter type of cages are mainly used in open ocean culture centers (in terms of swell and currents), while the first two are set up in protected or semi-open environments on the surface.

Copper Alloys

4. *What are the traditional materials available for cage/mesh construction in aquaculture?*

   Materials generally used in the net/mesh construction include synthetic fibers such as nylon, polyester, polypropylene, polyethylene, plastic-coated wire, rubber and galvanized steel. Materials are generally chosen based on application needs such as design feasibility, material resistance, costs and abrasion resistance.

5. *What types of copper alloys are used in aquaculture?*

   Copper-zinc alloys are common in aquaculture. Copper-nickel and copper-silicon alloys are also being tested. Each alloy has the inherent capacity to reduce biological contamination, fouling (unwanted accumulation of algae and other organisms on the net surface), diseases, the need for antibiotics for internal parasites, and treatments such as peroxide for ecotoparasites. Because fouling does not adhere, meshes remain clean, thus keeping a constant circulation of water and a higher degree of Dissolved Oxygen (DO).

[1] http://www.fao.org/fishery/gisfish/cds_upload/1157119747117_Optim_Tenerife.pdf

6. *How do copper alloys act in marine environments?*

The antimicrobial, fungicidal and algicidal properties of copper alloys significantly reduce fouling, which may be defined as the accumulation, adhesion and growth of unwanted microorganisms, algae, marine invertebrates (e.g., mollusks) and other organisms to the marine structures (nets). Because the growth of microorganisms is inhibited (biofilm layer), the nets constructed of copper alloys avoid the necessary and expensive mesh/net changes and greatly reduce the need for and prolong the intervals between periodic cleaning, thus promoting a cleaner and healthier environment for aquaculture.

Copper alloys resist corrosion in marine environments, which reduces the likelihood of mechanical failure or predation events.

Copper Meshes

7. *When were the first meshes developed?*

Copper-alloy nets have been used in the aquaculture industry for 25 years. The first mesh/net manufactured from copper alloys was built in Japan in the 1990s. Manufacturing began in Chile in 2008. The aquaculture industry is expanding the use of large-commercial scale nets and structural material in farming operations around the world.

8. *Are these meshes manufactured only with copper?*

Conventional metal meshes used in the marine environment have been made of various steel types, usually galvanized with zinc and/or coated with plastics, polymers, etc. The new uncoated metal meshes are manufactured from materials made from copper alloyed with a variety of other nonferrous metals, such as zinc (currently used at a commercial scale), silicon (silicon bronze wire is commercially available and is being formed into meshes now being used to develop new net designs), and nickel (still under study for aquaculture uses). Small amounts of other metals are added to these alloys to optimize properties. The composition of alloys may vary depending on the features and functionality given to the mesh/net.

Biocide Effect

9. *Are they able to prevent the ISA (infectious salmon anemia) virus?*

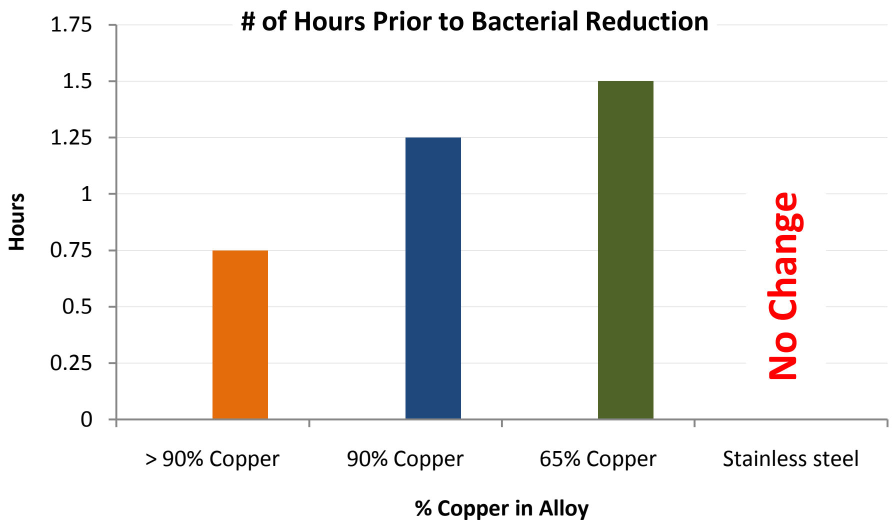
At this stage in the development and testing of copper mesh nets, their ability to prevent or inhibit ISA is not specifically known. However, copper alloys have the proven ability to inhibit a variety of infectious microbes in human health protection applications (these involve inoculating copper samples in air and measuring survival over time; data was not obtained in aqueous environments), and initial tests against bacterial pathogens in aquaculture have been promising (see below), so there is reason for optimism with regard to inhibiting ISA contagion in aquaculture.

A variety of research shows that copper alloys can inactivate the influenza A[2] virus when used in health care applications such as touch surfaces in hospitals. However, scientific results supporting the inactivation of the ISA virus in marine applications are not yet available, although its structure is similar to Influenza A.

The biocidal effect of copper alloys on *Listeria monocytogenes*[3,4] and other critical pathogens[5] has also been demonstrated.

[2] "Inactivation of Influenza A Virus on Copper Versus Stainless Steel Surfaces." J.O. Noyce, H. Michels and C.W. Keevil, *Applied and Environmental Microbiology*, April 2007, p. 2748-2750.
[3] "Antimicrobial Effects of Copper and Brass Ions on the Growth of Listeria Monocytogenes at Different Temperatures, ph and Nutrients." Aisha Abushelaibi, Dissertation submitted to the Graduate Faculty of the Louisiana State University, August 2005.
[4] "Survival of Listeria Monocytogenes Scott A on Metal Surfaces. Implications for Cross-Contamination." Sandra A. Wilks et al., *International Journal of Food Microbiology*, 2006.
[5] "Disminución de Tasas de Infección en Hospitales e Institutos de Salud—El rol de Las Aleaciones de Cobre en El Combate Contra Los Organismos Infecciosos." *Biohealth Partnership*, Edición 2, Marzo 2009.

Michels *et al.* (2005) assessed the inhibitory effect of different copper alloys as solid surfaces (for healthcare applications), which tends to decrease as the copper content is reduced. The antimicrobial efficiency of 25 copper alloys as solid surfaces was analyzed for *Escherichia coli* at 4°C and 20°C. Copper, brass (copper-zinc), bronze, copper-nickel, copper-nickel-zinc, stainless steel, polyethylene and stainless steel with silver ions were studied. Results showed the inhibitory effect decreasing as the amount of copper in the alloy is reduced. The most effective alloys in the reduction of bacteria of *Listeria monocytogenes* were the surfaces made up from a percentage >90%copper. In such alloys the quantity of bacteria remaining on dry, solid surfaces was reduced to 1.5 – 2 log units after 45 minutes and to zero after 60 minutes, unlike alloys that are 90% copper and 10% nickel and alloys made up from 65% copper, 17% zinc and 18% nickel, which caused a bacterial reduction at 75 and 90 minutes, respectively. Finally, the stainless steel surface showed no bacterial decrease after 90 minutes (Michels *et al.*, 2005).



In Noyce *et al.* (2005)[6], where a comparison of three surfaces was carried out (100% copper, copper-zinc, 80% copper and 10% zinc, and stainless steel) using three strains of meticillin-resistant *Staphylococcus aureus* (MRSA) at 20°C, the 100% copper surface caused a bacterial decrease after approximately 30 minutes and total elimination after 45, 60 and 90 minutes. Notwithstanding, the copper-zinc alloy showed a bacteria reduction after a considerably longer period of time (3 hours) and total elimination after 4.5 hours of exposure.

10. *What is fouling or biofouling?*

Fouling is a significant problem in aquaculture. It occurs in marine environments on material structures that are not copper alloys, including cage and net surfaces.

Measurements taken in an aquaculture operation in Tasmania showed the open area of a submerged nylon mesh decreased by 37% after only seven days as a result of fouling.

The biofouling process begins when organic matter, bacteria, protozoa, algae, and marine invertebrate larvae successively adhere to and grow on surfaces submerged in marine environments (e.g., netting in aquaculture). Biofouling has strong negative impacts on aquaculture operations. Water flow, dissolved oxygen and nutrient exchange are inhibited due to clogged nets in fish pens. The end result is often stressed fish, which expend more energy on swimming to seek dissolved oxygen and metabolic functions and less on growth. They become more susceptible to infections, such as netpen liver disease, amoebic gill disease, parasites and, in the case of shellfish, poisoning by phytoplankton. Other negative impacts include increased fish mortalities,

[6] "Potential Use of Copper Surfaces to Reduce Survival of Epidemic Meticillin-Resistant Staphylococcus Aureus in the Healthcare Environment." Noyce J., Michels H. and Keevil W. *Journal of Hospital Infection*, 2005. 63, 289-297.

premature fish harvesting, reduced fish product values and profitability, and an adversely impacted environment near aquaculture operations.

Biofouling adds enormous weight to submerged netting. This extra burden often results in net breakage and additional maintenance costs.

To combat the effects of fouling on nets and fish, chemical products (with a resulting negative impact on the aquatic environment) and antibiotic products (that may have effects on the health of consumers in the long term) must be applied. In other cases, the most common solution is to use antifouling coating (especially on synthetic netting); however, this offers limited resistance, only lasting from several weeks to six or eight months. The efficacy of antifouling solution depends on the number of washings the net is subjected to as well as how it is used, including installation and removal.

11. *What is the effect of copper alloys on fouling?*[7]

Aquaculture is currently facing the challenge of sustainability, which includes the maintenance of clean, well-fed, healthy fish in environments that avoid overcrowding. Fish remain healthy in nets and structures built from copper alloys due to their anticorrosion, inherent strength and antifouling properties.

Research shows the resistance of copper to fouling, even in mild waters, results from:

a. A retarding sequence of colonization through the formation of protective "patina" coatings and slow release of antimicrobial copper ions, thereby inhibiting the attachment of microbial layers to marine surfaces
b. Separating layers that contain corrosion products and the spores of juveniles or macro-encrusting organisms

The most important requirement for optimum resistance to fouling is that copper alloys must be freely exposed and electrically isolated from galvanically less noble alloys and cathodic protection. Otherwise, the less noble alloys and cathode protection will prevent the natural release of copper ions from superficial patina layers and, therefore, reduce fouling resistance.

As temperatures increase and water velocity decreases, fouling rates dramatically rise. However, copper's resistance to fouling has been observed even in temperate waters. Studies in La Herradura Bay, Coquimbo, Chile, where fouling conditions are quite extreme, have shown the copper-nickel alloy (90 percent copper and 10 percent nickel) inhibits fouling by macro-encrusting organisms[8].

12. *Do antifouling properties of copper alloys used in meshes disappear with time?*

Antifouling properties do not decrease with time. The mesh is manufactured completely from alloy. It is not coated or covered in an alloy that wears or corrodes over time nor will it leach like an antimicrobial substance in the surface layer of paint.

Use

13. *Is copper based netting affected by corrosion when used in seawater?*

In general, copper alloys have a long history of use in sea water because they show low corrosion. Different experiments carried out using nets at a 10 m depth have shown there is a higher corrosion effect close to the water line, which may extend to 200 mm in depth. However, corrosion significantly decreases at higher depths, with maximum values of 0.1 mm/yr in the net bottom.[9] [10].

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[7] http://www.copper.org/Applications/cuni/txt_references.html#General.
[8] "Environmental Performance of Copper Alloy Mesh in Marine Fish Farming: The Case for Using Solid Copper Alloy Mesh." The International Copper Association, Ltd., November 18, 2009 (www.copper.org).
[9] "Corrosion Behavior of Copper Alloys used in Marine Aquaculture." The International Copper Association, Ltd., June 26, 2009 (www.copper.org).

14. *What is the useful life of copper based netting?*

Commercial experiences in Japan and Australia show copper-alloy nets and meshes last at least 60 months. After this point they can be fully recycled.

15. *How is copper based netting maintained?*

Maintenance of this technology might include at two cleanings per year of macroalgae or other inorganic material (plastic wastes) that cling to the mesh and must be removed so they will not generate fouling elements.

16. *Are there any hydrodynamic differences between copper and traditional mesh?*

Experiments conducted by the University of New Hampshire (Decew, J. et al. 2007)[11] show that the drag coefficients of copper-nickel alloy meshes (90/10), based on a projected area of the galvanized steel and copper-nickel alloy, were, in general, lower than that of normal twine netting. At a speed of one m/s, twine netting had an overall drag coefficient of around 1.13 (Fullerton et al., 2002)[12]. The Cu-Ni net had a similar coefficient of drag to the twine net, although the overall drag force was 24%less. Some of the excess drag can be attributed to the solidity difference; however, it was hypothesized that twine netting vibrates more than its metallic counterpart, causing the drag to increase (Beveridge 1996)[13]. There is an additional small increase in drag when deployed due to the need to use larger buoyancy floats to support the heavier metal meshes.

More importantly, this type of technology allows a minimum reduction of the confining volume (weight and trawling effect) compared to traditional nets with nylon panels.

There are some anticipated differences between the copper release of a copper-alloy net and a traditional net with antifouling coatings. Copper in its solid metal form is chemically insoluble. This does not mean copper will not be released from a metal piece submerged in water, but that the release kinetics is extraordinarily slow. The best example of this is the use of copper pipes in building construction. Copper pipes are widely accepted around the world, although clear, well-defined limits have been established to regulate a safe level of copper in drinking water for human consumption. This implies the potential biological effect (positive or negative) of a metal is not indirectly related to the total concentration in the water, but it is significantly modified by the form of the metal and the physical-chemical characteristics of the water in a given site.

Thus, the conventional practice of using synthetic fiber netting covered by copper-based antifouling paint represents a potential for significantly higher level of copper exposure for the aquatic ecosystems than the use of metal copper nets. Copper-based antifouling coatings basically correspond to copper salts embedded in an organic matrix, which act through the release of ionic copper to the immediate aquatic surroundings, thus causing a toxic effect on fouling and, potentially, other organisms. Experiments under realistic marine conditions are now underway to quantify the differences in the copper release rates of copper-alloy meshes vs. antifoulant-coated nylon nets.

Additionally, raft reels with nylon nets using antifouling coating need predator nets (anti-predator nets), which in turn will increase the release of copper compared to a raft with a copper-alloy mesh, where predator nets are not necessary.

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[10] Additional information about the alloy can be found on www.mitsubishishindoh.com/en/urphys.htm.
[11] "Measurement of Drag Force Acting on Copper Nickel Alloy and Galvanized Steel Net Panels." Judson, Decew et al., Open Ocean Aquaculture Engineering Project, University of New Hampshire, Durham, NH 03824, 2006.
[12] "Measurement of Drag Force Acting on Fish Cage Net Panels." Fullerton, B., M.R. Swift, and K. Baldwin, 2002, University of New Hampshire.
[13] M.C.M. Beveridge: Cage Aquaculture.—352 pp., 151 figs. Farnham, Surrey: Fishing News Books Ltd. 1987. ISBN 0 85238 148 4. Ł 21.00.

Construction and Installation

17. Where is copper based netting built?

Copper-zinc alloys are currently being developed for commercial use in aquaculture applications in Asia (Japan) and South America (Chile).

18. What countries are currently using copper based netting?

Cages/nets constructed with copper alloys are currently used in the aquaculture industry in Japan, Australia, China, U.S., Panama and Chile.

Japan: Ashimori Industry Co. has been designing and installing more than 300 nets for yellowtail farming since the 1990s.

Australia: Since 2005, Ashimori Industry Co., in Tasmania, has utilized 25 nets for Atlantic salmon farming. A 15% increase in the growth rate has been achieved.

Chile: In 2008 the first two nets were developed for Atlantic salmon culture. The first two circular submersible nets of 20 m in diameter were installed in 2010.

U.S.: The first copper-alloy net for cod farming was installed in 2009.

Panama: The first submergible net for crab eater was installed in 2009. Three cages with three different types of copper alloys were set up.

Impacts

19. Considering the current trends on sustainable aquaculture, how do these nets affect the environment?

Copper nets involve various environmental benefits, which include: preventing fish escapes, avoiding the use of antifouling coating, reducing truck and vessels movements associated with conventional net operations, and promoting the reduction of CO_2 emissions with respect to conventional technologies.

It has been shown that nets manufactured from copper alloys are 100 percent recyclable. Recent analysis on the life cycle of copper showed its production releases less CO_2 to the atmosphere than steel, aluminum and nickel extraction, and its recycling generates less CO_2 than the production of virgin copper.

With more net pens being manufactured and supplied at a large scale in the aquaculture industry, a higher portion of the metal used is expected to recycled, thus reducing the emissions of greenhouse effect gases and the energy incorporated in the material[14].

20. Has the use of copper alloys in the aquaculture industry been analyzed within the framework of the new regulations for Sustainable Aquaculture?

The International Copper Association (ICA), within the framework of the Aquaculture Dialogues appointed by the World Wildlife Fund (WWF), has actively participated and identified the following seven key aspects where the use of copper alloys in salmon culture may be beneficial for the industry:[15]

a. *Benthic impacts and site selection (WWF):* Lower FCRs due to lower stress and higher dissolved oxygen levels, thus reducing the feed consumption for the production of equal biomass (ICA).

b. *Chemical supplies (WWF):* Reduces the use of chemical products during the elimination of parasites. Reduces the use of antibiotics; avoids the use of antifoulants that flake off the nets and accumulate in the benthos. (ICA).

[14] EcoSea Farming S.A. (www.ecosea.cl).

[15] "Environmental Performance of Copper Alloy Mesh in Marine Fish Farming: The Case for Using Solid Copper Alloy Mesh." The International Copper Association, Ltd., November 18, 2009 (www.copper.org).

c. *Diseases/parasites (WWF):* The absence of fouling eliminates the nearby habitats that may harbor early life stages of pathogens and parasites near fish (ICA).

d. *Escapes (WWF):* Better predation resistance (ICA). This eliminates the need to deploy (and maintain) a separate nylon predator net.

e. *Feed (WWF):* The higher conversion rate and low mortality reduces the feed consumption for the production of equal biomass (ICA).

f. *Nutrient load and load bearing capacity (WWF):* Submersible cages manufactured using copper material (netting) are ideal for the use in open ocean, where the currents are stronger, the waves are larger and depth is greater, which causes the dispersion of excess feed and fish waste, and where the antifouling performance decreases unwanted changes and avoids net cleaning (ICA).

g. *Social Issues (WWF):* Copper alloys greatly reduce the need for divers to clean and/or change nets, thus improving the safety of workers. The industry is developing open ocean sites with automated feeding and the integration of renewable energy sources (ICA).

21. Are there any negative impacts on the environment?

Based on metal loss observations of copper mesh cages now in the field, copper meshes appear to release less copper to the environment than antifouling-coated nylon netting. Further, there are no apparent adverse effects on biota outside the copper mesh nets in the field.

Cost

22. What is the price relation between copper and traditional meshes?

Evaluations of the economic impact involved in the use of this type of mesh and nets in the aquaculture operation are currently being carried out. Price is not an indicator in itself. Thus, all benefits involved in the use of these materials must be assessed, considering improvements to productivity.

Advantages

23. What are the advantages and benefits involved in copper meshes compared to traditional meshes?

Benefits may be arranged in the following categories[16]:

a. *Environmental Benefits*:

- Prevents fish escapes
- Avoids the use of antifouling coatings
- Reduces truck and vessel movements associated with the operation of conventional nets
- 100 percent recyclable once the life cycle is completed
- Contributes to the reduction of CO_2 emissions compared to the conventional technology

b. *Productive and Operational Benefits:*

- Mesh change is not required for five years (conventional meshes involve changes in a period of two – four months)
- Consequent reduction of fish management, which in turn leads to a reduction in damage due to stress and a decrease in fish mortality

[16] EcoSea Farming S.A. (www.ecosea.cl).

- Copper's natural properties reduce accumulation of fouling waste and organic matter on aquaculture enclosures to create healthier conditions for raising fish (in some occasions, one extraction or removal once or twice a year helps to extract all algae that may be trapped by mechanical tangling), thus reducing the parasite and pathogen presence
- Significant reduction in cleaning frequency of the mesh (once or twice a year), depending on the site conditions; improvement of water flow and oxygenation, through constant opening of the mesh, consequently improving fish health and growth rates
- Decrease and avoidance of losses and damages due to predator attacks (sea lions, seals, sharks)
- Predator nets are not needed
- Significant reduction of diving frequency and depth
- Deformation reductions and maintenance of the constant net, thus the density remains equal to the real density
- Can be installed in current pen technology used in the aquaculture industry, involving very few modifications
- They require less diving hours, reduce costs and improve the security of workers
- Eliminate the need for additional nets for changes

c. *Proven Experience and Results:* Van Diemen Aquaculture[17], located in Tasmania (Australia) has been using copper-alloy mesh technology since 2005 for growing Atlantic salmon, where significant improvements both in fish health and production costs have been achieved. EcoSea Farming S.A. in Chile has 60 copper-alloy mesh enclosures in operation.

- Feed conversion rate (FCR) improved by 13% during the last three years
- Mortality rates reduced 50 percent (from 18 – 20% without copper, down to 8%)
- Feed cost reduced by 15% (Chile) and 6% (Australia)
- Mesh cleaning reduced to once or twice per year
- Decrease loss and attacks from predators from 5 – 10% to near zero

Disadvantages

24. What are the disadvantages involved in the use of copper meshes?

A potential disadvantage (not yet proved) is the cost involved with the initial purchase of this type of product when compared to traditional synthetic fiber meshes. Therefore, the option to lease a net is currently available, with or without a purchase option.

Other Uses for Aquaculture Industries

25. Besides meshes/nets/cages, what other applications can be found in the aquaculture industry?

The combination of antimicrobial and corrosion resistance properties makes copper alloys a material sought for different applications in marine environments, such as tubes for condensers, inlets, filters, vessel hauls, structures and pisciculture tank coverings.

[17] "Environmental Performance of Copper Alloy Mesh in Marine Fish Farming: The Case for Using Solid Copper Alloy Mesh." The International Copper Association, Ltd., November 18, 2009 (www.copper.org).

Applications in Other Industries

26. *Considering the antimicrobial effect, is copper currently used in other applications?*

The U.S. Environmental Protection Agency (EPA) has registered nearly 300 copper alloys as antimicrobial materials effective against six significant human pathogens (*Staphylococcus aureus*, MRSA, VRE, *E. coli* O157:H7, *Enterobacter aerogenes* and *Pseudomonas aeruginosa*), including the MRSA bacteria, which is multi-resistant to various antibiotics. When cleaned regularly, products made from uncoated, EPA registered copper alloys can claim to kill greater than 99.9% of the six registered bacteria within two hours. Independent laboratory tests published in peer-reviewed journals have also shown copper is effective against many bacteria, fungi and viruses. (At the present time, because of time and budget restraints, EPA registration for Influenza A has not been pursued.)

This has lead to the ongoing development of different applications (contact surfaces) in the following sectors[18]:

- Health
- Food and Hotels
- Public and Educational Sectors
- Public Transportation
- Sport facilities
- Air-conditioning equipment and systems
- Other uses as contact surfaces

Additional Information

27. *Where can I find further information on the nontraditional use of copper?*

A list of resources and websites referenced in this document is provided below.

a. *Documents on copper alloy uses for the Aquaculture Industry:*

- "Design Guide-Copper Alloy Mesh in Marine Aquaculture." International Copper Research Association (INCRA), 1984, 704/5.
- "Metal Corrosion in Boats." Nigel Warren and Adlard Coles. *Nautical*, 1998.
- *Galvanic Corrosion: A Practical Guide for Engineers*. R. Francis. NACE Press, 2001.
- *Marine Corrosion Causes and Prevention.* F. LaQue. John Wiley and Sons, 1975.
- *The Selection of Materials for Seawater Cooling Systems: A Practical Guide for Engineers*. R. Francis. NACE Press, 2006.
- "Guidelines for the Use of Copper Alloys in Sea Water." A. Tuthill. CDA/ Nickel Institute Publication, 1987.
- "The Brasses: Properties and Applications." CDA UK Publication 117.
- SINTEF report: Application of Brass Net Cages in Norwegian Aquaculture—Environmental Analysis, Project number 840145.01 April 2005.

[18] The Official Brand of the World's Most Effective Antimicrobial Touch Surface Material. (http://www.antimicrobialcopper.com/us/markets--applications.aspx).

- SINTEF report: Application of Brass Net Cages in Norwegian Aquaculture—Strength Analysis, Project number 840145.01 June 2005
- "Copper Levels in the Muscle and Liver Tissues of Farmed Chinook Salmon." Peterson, L. K., J. M. D'Auria, B. A. McKeown, K. Moore and M. Shum, 1991.
- "Copper in the Ocean Environment." Neal Blossom, American Chemet Corporation.
- ICA Project 438: Experimental Usage of Copper Nickel Alloy Mesh in Aquaculture. Mario E. Edding, Hector Flores, Claudio Miranda, Universidad Católica del Norte, July 1995.
- Antifoulings: The Legislative Position by Country, Key Points Summary." (Latest update at www.copperantifouling.com)
- ICA Report: "Environmental Performance of Copper Alloy Mesh in Marine Fish Farming: The Case for Using Solid Copper Alloy Mesh." The International Copper Association, Ltd., November 18, 2009.

b. *Websites:*

- http://www.copper.org/
- http://www.antimicrobialcopper.com/
- www.coppernickel.org/