**Table S1.** An overview of common macrofouling organisms in marine shellfish culture, their documented adverse impacts, region of occurrence, shellfish species affected, and key references (updated from Fitridge et al. 2012).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fouling organism** | **Range of known impacts** | **Region** | **Shellfish species affected** | **Author(s)** |
| **Chordata: Ascidiacea***Ascidiella aspersa**Botrylloides violaceus**Botryllus* *schlosseri**Ciona intestinalis**Clavelina lepadiformis**Corella eumoyata**Dicarpa* sp.*Didemnum perlucidum**Didemnum* sp.*Didemnum vexillum**Diplosoma* sp.*Diplsomosa listerianum**Herdmania momus**Pyura pachydermatina**Microcosmus exasperatus**Molgula citrina**Mogula manhattensis**Styela clava**Styela* *plicata**Trididemnum cereum* | Physical disruption to opening and closing of valvesReduced sizeReduced growth Reduced flesh weight Reduced conditionMortalityCompetition for foodStock losses | AustraliaBrazilCanadaChinaFrench PolynesiaGreeceIndiaIrelandJapanNetherlandsNew ZealandNorwayPersian GulfSpainSwedenUSA | *Mytilus edulis**Perna canaliculus**Perna perna**Pinctada radiata* (=*fucata*)*Pinctada maxima**Pinctada martensi* (=*fucata*)*Pinctada fucata**Pinctada margaritifera**Mytilus galloprovincialis**Crassostra gigas**Kappaphycus alvarezii**Argopecten irradians irradians* | Takemura and Okutani (1955); Miyauti (1968); Alagarswami and Chellam (1976); Mohammad (1976); Dharmaraj et al. (1987); Chengxing (1990); Doroudi (1996); Carver et al. (2003); Coutts and Sinner (2004); Bourque et al. (2005); Mallet and Carver (2006); Forrest et al. (2007); Guenther and de Nys (2006); LeBlanc et al. (2007); Locke et al. (2007); Bonardelli (2008); Denny (2008); Ramsay et al. (2008); Daigle and Herbinger (2009); Gittenberger (2009); Rocha et al. (2009); Paetzold and Davidson (2010); Comeau et al. (2012); Kripa et al. (2012); Rolheiser et al. (2012); Woods et al. (2012); Antoniadou et al. (2013); Bullard et al. (2013); Fletcher et al. (2013); Sievers et al. (2013); Lacoste, Gueguen, et al. (2014); Lacoste, Le Moullac, et al. (2014); Sievers et al. (2014); Tettelbach et al. (2014); Holthuis et al. (2015); Marroig and Reis (2016); Atalah et al. (2016); Davidson et al. (2016); Watts et al. (2015); Casso et al. (2018); Palanisamy et al. (2018)  |
| **Turbellaria:** **Polycladida***Imogine mcgrathi**Stylochus* sp.*Stylochus matatsai**Stylochus frontalis* | Mortality | AustraliaMexico | *Crassostrea rhizophorae**Mytilus galloprovincialis**Pinctada margaritifera**Pinctada mazatlantica* | Littlewood and Marsbe (1990); Newman et al. (1993); Monteforte and Garcia-Gasca (1994); Pit and Southgate (2003) |
| **Annelida: Polychaeta***Boccardia knoxi**Hydroides dianthus**Hydroides elegans**Hydroides norvegicus**Platynereis australis**Polydora hoplura**Polydora websteri**Polydora ciliata**Polydora vulgaris**Pomatoceros caeruleus**Pomatoceros taeniata**Pomatoceros triqueter**Pseudopotamilla reniformis**Spirorbis* sp. | Blisters in nacreous layerWeakened shellDevaluationMortality | Arabian GulfAustraliaGreeceIndiaIndian OceanJapanNew ZealandRed SeaUKUSA | *Haliotis* spp.*Mytilus edulis**Pinctada fucata**Pinctada margaritifera**Mytilus galloprovincialis**Perna canaluculus* | Crossland (1957); Mohammad (1972); Blake and Evans (1973); Alagarswami and Chellam (1976); Mohammad (1976); Dharmaraj and Chellam (1983); Velayudhan (1983); Dharmaraj et al. (1987); Arakawa (1990); Wada (1991); Doroudi (1996); Taylor et al. (1997); Campbell and Kelly (2002); Lleonart et al. (2003); Kripa et al. (2012); Antoniadou et al. (2013); Sievers et al. (2014); Atalah et al. (2016); Watts et al. (2015)  |
| **Algae***Ceramium* sp.*Cladophora* sp.*Codium fragile*Cyanobacteria*Gracilaria verrucosa**Undaria pinnatifida**Ulva rigida**Chaetomorpha* sp. *Cladophora vagabunda Ulva lactuca**Ulva flexuosa* *Hypnea musciformis**Padina* sp.*Porphyra* sp.*Colpomenia* sp.*Acanthophora spicifera**Spuridia* sp.*Sargassum* sp.*Amphiroa* sp.*Jania* sp.*Hincksia* sp.*Hypnea spinella* | Shell erosionLost stockOvergrowthSmothering | BrazilCanadaGreeceIndiaNew Zealand | *Mytilus edulis**Perna canaliculus**Pinctada margaritifera**Pinctada fucata**Mytilus galloprovincialis**Kappaphycus alvarezii* | Mao Che et al. (1996); Garbary and Jess (2000); Naylor et al. (2001); Provan et al. (2005); Forrest and Blakemore (2006); Sharp et al. (2006); Wells et al. (2009); Kripa et al. (2012); Woods et al. (2012); Antoniadou et al. (2013); Sievers et al. (2014); Marroig and Reis (2016); Pochon et al. (2015); Atalah et al. (2016); Watts et al. (2015) |
| **Porifera***Callyspongia fibrosa**Cliona celata**Cliona dissimilis**Cliona margaritiferae**Cliona orientalis**Cliona* sp.*Cliona vastifica**Dysidea* sp.*Hymeniacidon* sp.*Leucosolenia* sp.*Pione velans* | BrittlenessHinge instabilityBlister formationShell damageShell deformityMortality | AustraliaBrazilFrench PolynesiaGreeceIndian OceanPersian GulfRed Sea | *Kappaphycus alvarezii**Chlamys islandica**Ostrea edulis**Pinctada fucata**Pinctada margaritifera**Pinctada margaritifera* var. *cumingii**Pinctada radiata**Placopecten magellanicus**Mytilus galloprovincialis* | Korringa (1952); Crossland (1957); Evans (1969); Mohammad (1972); Alagarswami and Chellam (1976);Mohammad (1976); Thomas (1979); Dharmaraj and Chellam (1983); Velayudhan (1983); Dharmaraj et al. (1987); Pomponi and Merritt (1990); Barthel et al. (1994); Doroudi (1996); Mao Che et al. (1996); Wesche et al. (1997); Moase et al. (1999); Rosell et al. (1999); Fromont et al. (2005); Antoniadou et al. (2013); Lacoste, Le Moullac, et al. (2014); Marroig and Reis (2016) |
| **Mollusca: Bivalvia***Chama pacifica**Crassostrea* sp.*Crassostrea* *rhizophorae**Hiatella arctica**Isognomon* sp.*Limaria orientalis**Lithophaga* sp.*Martesia* sp.*Modiolarca impacta**Musculus impactus**Mytella charruana**Mytilus* sp.*Mytilus galloprovincialis**Ostrea edulis**Ostrea equestris**Pinctada maculata**Pinctada* sp*.**Pinna* sp.*Perna perna**Pteria* sp.*Saccostrea* sp. | Physical disruption to opening and closing of valvesDamage to shellRecession of shell growthShell deformityMortalityCompetition for food and spaceReduced condition | AustraliaBrazilFrench PolynesiaGreeceIndiaIndonesiaNew ZealandPersian GulfRed Sea | *Crassostrea* *rhizophorae**Pinctada fucata**Pinctada margaritifera**Pinctada maxima**Pinctada radiata**Perna canaliculus**Mytilus galloprovincialis**Nodipecten nodosus**Kappaphycus alvarezii* | Takemura and Okutani (1955); Crossland (1957); Alagarswami and Chellam (1976); Dharmaraj and Chellam (1983); Doroudi (1996); Taylor et al. (1997); Guenther et al. (2006); Carraro et al. (2012); Woods et al. (2012); Antoniadou et al. (2013); Lacoste, Le Moullac, et al. (2014); Marroig and Reis (2016); Atalah et al. (2016); Watts et al. (2015); Lacoste et al. (2016); Forrest and Atalah (2017); South et al. (2017); das Chagas et al. (2018) |
| **Cnidaria: Hydrozoa***Amphisbetia bispinosa**Ectopleura crocea**Ectopleura* *larynx**Ectopleura* *warreni**Eutima japonica**Hydractinia angusta**Obelia* *bidentata**Obelia* sp.*Pinnaria disticha**Tubularia crocea**Tubularia* sp. | SmotheringRecession of shell growthDevaluationCompetition for food and spaceStressDisruption to feedingPhysical disruption to opening and closing of valvesFacilitate settlement of other foulersDeter shellfish recruitment | AustraliaBrazilCanadaGreeceJapanNew ZealandUSA | *Adamussium colbecki**Mizuhopecten yessoensis**Mytilus edulis**Mytilus gallopronvincialis**Perna canaliculus**Placopecten magellanicus**Kappaphycus alvarezii* | Claereboudt et al. (1994); Cerrano et al. (2001); Heasman and de Zwart (2004); Gretchis (2006); Guenther and de Nys (2006); Baba et al. (2007); Fitridge (2011); Antoniadou et al. (2013); Bullard et al. (2013); Fitridge and Keough (2013); Sievers et al. (2014); Marroig and Reis (2016); Atalah et al. (2016); Watts et al. (2015) |
| **Cnidaria: Anthozoa***Aiptassiogeton hyalnus**Corynactis australia**Aiptasia* sp. |  | French PolynesiaGreeceNew Zealand | *Mytilus galloprovincialis**Pinctada margaritifera**Perna canaliculus* | Antoniadou et al. (2013); Lacoste, Gueguen, et al. (2014); Atalah et al. (2016) |
| **Arthropoda:** **Maxillopoda***Amphibalanus amphitrite**Balanus amphitrite communis**Balanus amphitrite variegates* *Balanus trigonus**Balanus* sp.*Megabalanus* sp*.**Perforatus perforatus* *Tetraclita* sp. | Physical disruption to opening and closing of valvesRecession of shell growthMortality | Arabian GulfAustraliaBrazilGreeceIndiaIndonesiaJapanNew ZealandPersian Gulf | *Kappaphycus alvarezii**Pinctada fucata**Pinctada martensi**Pinctada maxima**Pinctada radiata**Perna canaliculus**Mytilus galloprovincialis**Nodipecten nodosus* | Takemura and Okutani (1955); Miyauti (1968); Alagarswami and Chellam (1976); Mohammad (1976); Doroudi (1996); Taylor et al. (1997); de Nys and Ison (2004); Carraro et al. (2012); Kripa et al. (2012); Antoniadou et al. (2013); Marroig and Reis (2016); Atalah et al. (2016) |
| **Bryozoa***Bugula neritina**Bugula stolonifera**Crassimarginatella papulifera**Electra* sp*.**Leucosolenia* sp.*Schizosmittina cinctipora* | SmotheringCompetition for food and spaceDisruption to feedingPhysical disruption to opening and closing of valvesFacilitate settlement of other foulers | BrazilGreeceIndiaNew Zealand | *Perna canaliculus**Pinctada fucata**Mytilus* *galloprovincialis**Nodipecten nodosus* | Carraro et al. (2012); Kripa et al. (2012); Antoniadou et al. (2013); Marroig and Reis (2016); Atalah et al. (2016) |

**Table S2.** An overview of common macrofouling organisms in marine finfish culture, their documented adverse impacts, region of occurrence, fish species affected, and key references (updated from Fitridge et al. 2012).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fouling organism** | **Range of known impacts** | **Region** | **Fish species affected** | **Author(s)** |
| **Chordata: Ascidiacea***Ascidiella aspersa**Botrylloides* sp.*Botryllus schlosseri**Botryllus* sp*.**Chelyosoma* sp.Ciona intestinalis*Cnemidocarpa bicornuta**Styela* sp.*Styela* *plicata**Symplegma* sp.*Trididemnum* sp. | Net occlusionIncreased dragCage deformation and structural fatigueIncreased disease riskHarbouring of pathogens | CanadaMalaysiaNorwayUKUSA | *Epinephelus* sp.*Gadus morhua**Lates calcarifer**Lutjanus* sp.*Oncorhynchus tshawytscha* *Salmo salar**Siganus* sp. | Milne (1975b); Braithwaite et al. (2007); Chambers et al. (2012); Atalah et al. (2013); Bloecher et al. (2013); Edwards et al. (2015); Swain and Shinjo (2014); Madin and Ching (2015); Hellebø et al. (2017) |
| **Mollusca: Bivalvia***Arca auriculata**Barbatia sinenis**Chlamys transquebaricus**Crassostrea* spp.*Crassostrea madrasensis, Electroma georgiana**Hiatella arctica**Heteranomia squamula**Limnoperna fortune**Modiolus* sp.*Mytilus edulis**Mytilus galloprovincialis**Pecten maximus**Perna canaliculus**Perna viridis**Pinctada* spp*.**Pinctada chemnitzi**Pinctada vulgaris* *Pteria* sp*.**Saccostrea cucullate**Xenostrobus mangle* | Net occlusionIncreased drag Cage deformation and structural fatigueHarbouring of pathogens | AustraliaBrazilCanadaIndiaMalaysiaNorwaySingaporeUKUSA | *Epinephelus* sp.*Lates calcarifer**Lutjanus* sp.*Lutjanus argentimaculatus* *Oncorhynchus tshawytscha**Rachycentron canadum**Salmo salar**Signaus* sp.*Thunnus maccoyii**Trachinotus blochii* | Milne (1975a); Milne (1975b); Moring and Moring (1975); Lee et al. (1985); Cronin et al. (1999); Braithwaite et al. (2007); Greene and Grizzle (2007); Atalah et al. (2013); Bloecher et al. (2013); Edwards et al. (2015); Madin and Ching (2015); Hellebø et al. (2017); Gansel et al. (2017); Mhaddolkar et al. (2017); Godoy et al. (2018) |
| **Cnidaria: Anthozoa***Anthothoe albocincta**Bunodosoma sp.**Diadumene* sp.*Diadumene neozelandica Mimetridium cryptum* *Viatrix* sp. | Net occlusion Likely cause for skin lesions | New ZealandIndia | *Lates calcarifer**Lutjanus argentimaculatus**Oncorhynchus tshawytscha**Rachycentron canadum**Trachinotus blochii* | Atalah et al. (2013); Wybourne (2013); Atalah and Smith (2015); Mhaddolkar et al. (2017) |
| **Cnidaria: Hydrozoa***Bougainvilla* sp.*Ectopleura crocea**Ectopleura exxonia**Ectopleura* *larynx**Eudendrium* sp.*Eudendrium capillare**Garvei* sp.*Obelia* sp.*Obelia* *dichotoma**Obelia geniculata**Opercularella lacerate**Plumularia* sp.*Tubularia* sp.*Sarsia tubulosa* | Net occlusionIncreased drag Reduced water flowHarbouring of pathogensGill injuries | CanadaChinaIndiaIrelandMalaysiaNew ZealandNorwayUSA | *Gadus morhua**Lates calcarifer**Lutjanus argentimaculatus* *Oncorhynchus tshawytscha**Rachycentron canadum**Salmo salar Trachinotus blochii* | Hodson et al. (2000); Guenther et al. (2009); Madin et al. (2009); Guenther et al. (2010); Carl et al. (2011); Guenther et al. (2011); Baxter et al. (2012); Chambers et al. (2012); Atalah et al. (2013); Bloecher et al. (2013); Edwards et al. (2015); Gansel et al. (2015); Madin and Ching (2015); Hellebø et al. (2017); Mhaddolkar et al. (2017); Bi et al. (2018); Bloecher et al. (2018) |
| **Arthropoda: Crustacea***Balanus sp.* *Balanus amphitrite**Balanus eburneus**Semibalanus cariosus**Caprella sp.**Caprella mutica**Caprella linearis**Aeginia longicornis**Jassa falcata*  | Net occlusion | CanadaIndia MalaysiaNorway | *Gadus morhua**Lates calcarifer**Lutjanus argentimaculatus**Rachycentron canadum**Salmo salar**Thunnus thynnus**Trachinotus blochii* | Chambers et al. (2012); Bloecher et al. (2013); Edwards et al. (2015); Swain and Shinjo (2014); Madin and Ching (2015); Mhaddolkar et al. (2017) |
| **Bryozoa***Bowerbankia* sp*Bowerbankia imbricata**Bugula neritina**Cryptosula* sp.*Electra Pilosa**Membranipora membranacea* | Net occlusion Encrusting bryozoans provide attachment points for other organismsHarbouring of pathogens | IndiaNorwayMalaysiaUSA | *Lates calcarifer**Lutjanus argentimaculatus Rachycentron canadum**Salmo salar**Trachinotus blochii* | Bloecher et al. (2013); Swain and Shinjo (2014); Madin and Ching (2015); Hellebø et al. (2017); Mhaddolkar et al. (2017) |
| **Algae**Filamentous algae*Acrochaetium daviesii**Agloathamnion byssoides**Antithamnion* sp.*Antithamnion cruciatum**Bangia fuchsopurpurea**Bryopsis* sp.*Callithamniella tingitana**Callithamnion corymbosum**Ceramium* sp.*Ceramium diaphanum**Ceramium flaccidum**Chondria tenuissima**Cladophora* sp.*Cladophora dalmatica**Cyanophyceae**Derbesia tenuissima**Dasya ocellata**Desmarestia viridis**Diatomeae**Ectocarpus* sp.*Ectocarpus siliculosus**Enteromorpha* spp.*Enteromorpha clathrata**Erythrotrichia carnea**Falkenbergia rufolanosa**Feldmannia caespitula**Feldmania irregularis**Florideophyceae* sp.*Fosliella farinosa**Gracilaria* sp.*Laurencia obtusa**Lyngbya* sp.*Myrionema orbiculare**Pneophyllum fragile**Polysiphonia* sp.*Polysiphonia scopulorum**Polysiphonia stricta**Saccharina latissima**Spongomorpha* sp.*Spyridia filamentosa**Titanoderma pustulatum**Ulothrix* spp.*Ulva* spp.*Ulva multiramosa**Ulva prolifera**Ulvophyceae* sp.*Urospora peniciliformis**Wrangelia penicillata* | Net occlusionIncreased drag Cage deformation and structural fatigueRestriction of water exchangePoor water qualityLimited oxygen availabilityReduced waste metabolite removal | AustraliaCanadaCroatiaMalaysiaNorway UKUSA | *Dicentrachus labrax**Epinephelus* sp.*Lates calcarifer**Lutjanus* sp.*Oncorhynchus tshawytscha**Salmo salar**Signaus* sp.*Sparus aurata**Thunnus maccoyii* | Milne (1975a); Milne (1975b); Moring and Moring (1975); Hodson and Burke (1994); Cronin et al. (1999); Svane et al. (2006); Sliskovic et al. (2011); Bloecher et al. (2013); Edwards et al. (2015); Madin and Ching (2015); Gansel et al. (2017) |

**Table S3.** Statutory regulation and recommended best management practices associated with finfish aquaculture biofouling management.

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| **Country** | **Summary** | **References** |
| ASC | Salmon | **Recommended:** Copper treated nets must not be treated or high-pressure cleaned *in situ*. Low pressure cleaning of copper treated nets may be undertaken *in situ*. On land net cleaning sites must have suitable effluent treatment systems in place. Where copper treated nets are used, monitoring of copper levels outside the AZE must be undertaken and within acceptable limits. Any biocides used in net antifouling must be approved in legislation in the EU, USA or Australia. | ASC. (2017) |
| Seabass, Seabream and Meagre | **Recommended:** Any biocides used in net antifouling must be approved in legislation in the EU, USA, Australia or Japan. On land net cleaning sites must have suitable effluent treatment systems in place, including copper capture where copper is used. Biological waste must be stored and/or disposed of appropriately. | ASC. (2019) |
| Australia | National | **Statutory:** None identified**Recommended:** *In situ* cleaning to be undertaken in permitted areas within the marine farming lease only, in line with relevant regulations.Routine *in situ* cleaning of mature/extensive biofouling in place of earlier/better maintenance practices is not recommended. Where the discharged materials meet relevant standards, *in situ* cleaning is acceptable however methods should be adopted to ensure minimal release of biological material into the water. Methods should catch biofouled material with a diameter greater than 50 micrometres to minimise the release of viable biofouling organisms back into the environment. Collected debris must be disposed of on land following relevant waste disposal requirements. *In situ* cleaning should not be done within or beside areas of high conservation value. Where suspected invasive or non-indigenous species are identified during cleaning, this should be reported to the relevant authority and cleaning stopped.  |  NSPMMPI. (2013) Department of the Environment. and New Zealand Ministry for Primary Industries. (2015) |
| Tasmania | **Statutory:** Licences holders must adhere to any written requests regarding measures to mitigate against ecological effects from waste associated with fouling organisms. **Recommended:** Vacuum only *in situ* methods to be used on nets treated with antifoulant. Non anti-fouled nets can be cleaned using the vacuum and blasting techniques together. Cleaning frequency should increase during periods of high fouling. Positioning should be considered to minimise impact on caged fish. | Within marine farming licences;TSGA. (2013) |
| New South Wales | **Statutory:** Biofouling must be regularly removed. The impacts of biofouling management must be monitored following Water Quality and Benthic Environmental Monitoring Plans to mitigate potential impacts. In-site cleaning must be monitored for particulate impacts. Chemicals are not permitted in cleaning practices. **Recommended:** none identified | NSW Department of Primary Industries. (2018) |
| Canada  | Nova Scotia and New Brunswick  | **Statutory:** On-site cleaning of nets not recommended. *In situ* washing of lightly fouled nets is allowed for maintenance purposes. *In situ* washing must be done to maximize dispersal of waste materials away from nearby cages. Clean nets must be used at the beginning of each production cycle and replaced more often if necessary. No *in situ* net cleaning to be conducted at sites with sulphide concentrations over 3000μM. Biofouling control activities are accepted however the operator must take reasonable measures to mitigate risk of serious harm to commercial, recreational and Aboriginal fisheries and deleterious substances (pest control products or biochemical oxygen demanding matter) must not be deposited in managing biofouling.**Recommended:** None identified | Department of Environment and Local Government. (2012); Nova Scotia Fisheries and Aquaculture. (2018)Canadian Government. (1985) (amended 2016); Fisheries and Oceans Canada. (2015) |
| British Columbia | **Statutory**: Activities which result in serious harm to commercial, recreational or Aboriginal fisheries, or to fish that support these fisheries must not be undertaken, unless given permission to do so from a relevant authority. **Recommended:** None identified | Canadian Government. (1985) (amended 2016)) |
| Chile  | **Statutory:** Copper coated nets (and others coated in non-degradable or bio-accumulative toxic anti-foulants) must be cleaned on land-based facilities. When undertaking *in situ* cleaning using vacuuming systems with retention, no more than 20 days must pass between cleans from October to March, and no more than 2 months must pass from April to September. The retained material must be disposed of on land, following regulatory requirements. If these time periods are exceeded cleaning must be carried out on land or in boats, pontoons and other naval artefacts, with prior authorization of the Maritime Authority. When undertaking *in situ* cleaning with methods other than vacuum system with retention, no more than 15 days may pass between cleans from October to March, and no more than 2 months must pass from April To September. Only non-degradable or bio-accumulative toxic anti-foulants accredited by the relevant body can be used. **Recommended:** None identified | Ministerio de Economia (2001) (amended 2017)) |
| New Zealand | **Statutory:** None identified**Recommended:** Routine *in situ* cleaning of mature/extensive biofouling in place of earlier/better maintenance practices is not recommended. Where the discharged materials meet relevant standards, *in situ* cleaning is acceptable however methods should be adopted to ensure minimal release of biological material into the water. Methods should catch biofouled material with a diameter greater than 50 micrometres to minimise the release of viable biofouling organisms back into the environment. Collected debris must be disposed of on land following relevant waste disposal requirements. *In situ* cleaning should not be done within or beside areas of high conservation value. Where suspected invasive or non-indigenous species are identified during cleaning, this should be reported to the relevant authority and cleaning stopped.Regular cleaning and maintenance should be undertaken to minimise build-up of biofouling. Any new or innovative methods for reducing organics discharged during cleaning should be reported to AQNZ. Any new or notifiable pest species should be reported. In low-flow environments (<9.5cm s-1) and where nets are coated in copper anti-foulants, *in situ* cleaning should not be used, nets should be removed and cleaned on land. Copper based anti-foulants may cause less environmental risk than *in situ* washing. Nets should be cleaned often enough to ensure that water flow and dissolved oxygen concentrations inside the nets are not too much reduced. Dissolved oxygen concentrations should be ≥70% saturations inside the net-pens. | Department of the Environment. and New Zealand Ministry for Primary Industries. (2015)New Zealand Sustainable Aquaculture. (2015)(Sim-Smith and Forsythe 2013) |
| Norway | **Statutory:** Only approved anti-foulants can be used. Land-based net cleaning must not cause the release of hazardous chemicals at concentrations greater than the surrounding water, and any pollution caused must be negligible. The cleaning facilities discharge must not exceed 2kg Cu/yr. *In situ* cleaning is not regulated other than that the copper concentration in the sediment is monitored as to not exceed certain limits. **Recommended:** None identified | European Parliament. (1998)Norwegian Ministry of Climate and Environment (2004 (amended 2016))(Standard Norge 2016) NS 9410:2016 |
| Scotland | **Statutory:** Only approved anti-foulants can be used (copper oxide and dichlofluanid antifoulants). Controlled Activities Regulations (CAR) licence holders must comply with approved anti-foulant manufacturer's instructions. CAR licences provide any requirements associated with biofouling control.**Recommended:** Biofouling should not be allowed to build up so that water flow through cages is restricted. Where excessive biofouling is observed, this should be dealt with immediately. | European Parliament. (1998); SEPA. (2011) CoGP Management Group. (2015) |
| USA  | Florida | **Statutory**: The discharge of waste from *in situ* net cleaning should be avoided. The use strategies to reduce biofouling and the need for *in situ* cleaning should be adopted (eg cleaner fish, fouling resistant materials, net changing, rotating cage designs or anti-foulant coatings). Any anti-foulant coatings used must be reported to the relevant body before use. *In situ* methods must include strategies to prevent solids accumulating on the sea floor, or a reduction in water quality. Biocidal net cleaning methods are not allowed. **Recommended:** None identified | FDACS (2016) |

**Table S4.** An overview of common macrofouling organisms in marine seaweed culture, their documented adverse impacts, region of occurrence, seaweed species affected, and key references (updated from Fitridge et al. 2012). Note: The algae *Polysiphonia* (syn. *Neosiphonia*) *apiculate* and *Ulva prolifera* were given separate rows due to their specific impacts.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fouling organism** | **Range of known impacts** | **Region** | **Seaweed species affected** | **Author(s)** |
| **Chordata: Ascidiacea***Botrylloides* sp.*Botryllus* sp.*Ciona intestinalis* *Didemnum* sp. | Degradation in blade qualityMortalityReduced bio-mitigation capacityReduced biomass Reduced growth | BrazilDenmarkIndiaNorwayUK | *Kappaphycus alvarezii**Laminaria digitata**Saccharina latissimi* | Andersen et al. (2011); Marroig and Reis (2011); Veeragurunathan et al. (2015) Bruhn et al. (2016); Rolin et al. (2017) |
| **Annelida: Polychaeta**Flukeworms*Nereis* sp. |  | India | *Gracilaria dura* | Veeragurunathan et al. (2015) |
| **Algae***Acanthophora spicifera* *Acanthophora* spp. *Acrochaetium* sp. *Acrosorium corallinarum* *Antithamnionella* sp. *Bryopsis* sp. *Caulerpa racemosa* *Centroceras* sp*.* *Ceramium diaphanum* *Ceramium nodulosum**Ceramium rubrum* *Ceramium secundatum* *Ceramium* sp. *Chaetomorpha compressa* *Chaetomorpha crassa* *Chondracanthus tedii* *Chondria californica* *Chondrus crispus* *Cladophera* sp. *Cladophora pellucida* *Cladophora vagabunda* *Colpomenia sinuosa* *Cystoseira myrica* *Desmarestia* sp. *Dictyota cervicornis* *Dictyota dichotoma* *Dictyota* sp. *Ectocarpus acutus* *Ectocarpus* spp. *Enteromorpha intestinalis* *Entomorpha* sp. Filamentous algae *Fosliella* sp. *Giffordia* sp. *Gracilaria edulis* *Gracilariopsis tenuifrons* *Griffordia johnsoni* *Herposiphonia* sp. *Hincksia granulosa* *Hincksia mitchelliae* *Hydroclathrus clathratus* *Hydroclathrus* sp. *Hypnea musciformis* *Hypnea pannosa* *Hypnea* sp. *Hypnea spinella* *Hypnea valentiae* *Jania rubens* *Laurencia majuscula* *Laurencia snackeyi* *Liagora ceranoides* *Neosiphonia apiculata* *Neosiphonia savatieri* *Padina gymnospora* *Platymonas suecica**Polysiphonia flaccidissima* *Polysiphonia harveyi* *Polysiphonia* spp. *Rhizoclonium* sp. *Sahlingia subintegra* *Sargassum duplicatum* *Sargassum palgiophyllum* *Solieria tenera* *Spyridia* spp*.* *Streblonema* sp.*Turbinaria conoides* *Ulothrix flacca* *Ulva clathrate* *Ulva lactuca* *Ulva reticulata* *Ulva* spp. | Change in appearanceCompetition for light, substrate and nutrition.Decreased solar irradianceDegradation in blade qualityDiseaseHydrodynamic effectsIncrease in N content of biomass and P contentLoss of productivity by causing rafts to sinkMortalityReduced growthReduced photosynthesisReduced productionTissue degradation | BrazilCanadaChileChinaDenmarkIndiaIrelandIsraelJapanKoreaMadagascarMalaysiaNew ZealandNorwayPhilippinesSouth AfricaSpainSwedenTaiwan ThailandUKUSAVenezuela  | *Alaria esculenta**Chondracanthus chamissoi**Chondrus crispus**Gracilaiopsis lemaneiformis**Gracilaria chilensis**Gracilaria conferta**Gracilaria dura**Gracilaria ferox**Gracilaria fisheri* *Gracilaria foliifera**Gracilaria gracilis**Gracilaria multipartita**Gracilaria salicornia**Gracilaria* sp.*Gracilaria tenuistipitata**Gracilaria tenuistipitata**Gracilaria tikvahiae**Kappaphycus alvarezii**Laminaria digitata**Laminaria hyperborea**Saccharina latissimia**Undaria pinnatifida* | Edelstein et al. (1976); Shang (1976); Chiang (1981); Guiry and Ottway (1981); Hansen et al. (1981); Yoneshigue-Braga and Baeta Neves (1981); Shacklock and Doyle (1983); Hansen (1984); Ren et al. (1984); Bidwell et al. (1985); Lipkin (1985); Pizarro and Barrales (1986); Brinkhuis et al. (1987); Edding et al. (1987); Friedlander et al. (1987); Buschmann and Kuschel (1988); Santelices and Doty (1989); Friedlander et al. (1991); Kuschel and Buschmann (1991); Anderson RJ et al. (1992); Bravo et al. (1992); Chiang (1992); Dawes (1992); Friedlander (1992); Haglund (1992); Oliveira (1992); Rincones et al. (1992); Ugarte and Santelices (1992); Buschmann and Gomez (1993); Haglund and Pedersen (1993); Pickering et al. (1993); Pizarro and Santelices (1993); Santelices and Varela (1993); Buschmann et al. (1994); Anderson BC et al. (1998); Capo et al. (1999); Leonardi et al. (2006); Vairappan (2006); Vairappan et al. (2008); Vairappan et al. (2009); Andersen et al. (2011); Marroig and Reis (2011); Peteiro and Freire (2013); Ateweberhan et al. (2015); Marinho et al. (2015); Veeragurunathan et al. (2015); Marroig and Reis (2016); Macchiavello et al. (2017); Rolin et al. (2017); Walls et al. (2017); Chirapart et al. (2018); Kerrison et al. (2018) |
| *Polysiphonia* (syn *Neosiphonia*) *apiculata* | Distortion of thallusPrecursor for secondary bacterial infectionReduced growthScarcity or lack of availability of good quality propagules for re-planting purposesTissue degradationReduced carrageenan yield | IndonesiaMadagascarMalaysia PhilippinesTanzania | *Kappaphycus alvarezii* | Hurtado et al. (2006); Vairappan (2006); Vairappan et al. (2008); Hayashi et al. (2010); Borlongan et al. (2011); Vairappan et al. (2013); Ateweberhan et al. (2015); Borlongan et al. (2016); Tsiresy et al. (2016) |
| *Ulva prolifera* | Cause green tides | China | *Pyropia* (syn *Porphyra*) yezoensis | Liu et al. (2013); Fan et al. (2015); Keesing et al. (2016) |
| **Cyanobacteria***Lyngbya* *majuscule* *Lyngbya* sp.*Xenococcus* sp. | Tissue degradation | ChileIndia | *Gracilaria chilensis**Gracilaria dura* | Shang (1976); Hansen et al. (1981); Lignell et al. (1987); Leonardi et al. (2006); Veeragurunathan et al. (2015) |
| **Porifera***Haplosclerida* sp. |  | Brazil | *Kappaphycus alvarezii* | Marroig and Reis (2011) |
| **Mollusca: Bivalvia***Anomia ephippium**Hiatella arctica**Modiolus* sp.*Mytilus edulis*.*Mytilus* sp.*Perna perna* | Change in appearanceDegradation in blade qualityHydrodynamic effectsIncrease in N content of biomass and P contentMortalityReduced bio-mitigation capacityReduced biomass qualityReduced growth | BrazilDenmarkIndiaIrelandNorwayUK | *Alaria esculenta**Gracilaria dura**Kappaphycus alvarezii**Laminaria digitata**Saccharina latissimi* | Cancino et al. (1987); Bartsch et al. (2008); Andersen et al. (2011); Marroig and Reis (2011); Forbord et al. (2012); Marinho et al. (2015); Veeragurunathan et al. (2015) Bruhn et al. (2016); Rolin et al. (2017); Walls et al. (2017) |
| **Cnidaria: Hydrozoa***Kirchenpaueria pinnata**Obelia geniculata* | Colour abnormalities in algal tissuesDecreased productionDegradation of taste and qualityHydrodynamic effectsReduced bio-mitigation capacityReduced biomass qualityReduced growth | ChileDenmarkIrelandKoreaSpain | *Alaria esculenta**Gracilaria chilensis**Saccharina japonica**Saccharina latissimi**Undaria pinnatifida* | Park and Hwang (2012); Peteiro and Freire (2013); Bruhn et al. (2016); Walls et al. (2017) |
| **Cnidaria: Anthozoa***Boloceroides* sp. |  | India | *Gracilaria dura* | Veeragurunathan et al. (2015) |
| **Arthropoda: Maxillopoda***Balanus perforate**Balanus* sp. | Change in appearanceIncrease in N content of biomass and P content | DenmarkIndiaIreland | *Alaria esculenta**Gracilaria dura**Saccharina latissimi* | Marinho et al. (2015); Veeragurunathan et al. (2015); Walls et al. (2017) |
| **Bryozoa***Bowerbankia* sp.*Bugula neritina**Bugula* spp.*Crisia* sp.*Echinochalina* sp.*Electra pilosa**Electra pilosa**Membranipora mambranacea* | Change in appearanceDecreased flexibility of laminaDegradation in blade qualityHydrodynamic effectsIncrease in N content of biomass and P contentIncreased susceptibility to breakageMortalityReduced commercial value of biomass | BrazilChileIndiaIrelandNorway DenmarkUK | *Alaria esculenta**chamissoi**Chondracanthus**Gracilaria dura**Kappaphycus alvarezii**Laminaria digitata**Saccharina latissimi* | Bartsch et al. (2008); Andersen et al. (2011); Marroig and Reis (2011); Lüning and Mortensen (2015); Marinho et al. (2015); Veeragurunathan et al. (2015) Førde et al. (2016); Macchiavello et al. (2017); Rolin et al. (2017); Walls et al. (2017) |
| **Annelida: Polychaeta***Spirobranchus triqueter**Spirorbis carinatus* |  | Ireland | *Alaria esculenta* | Walls et al. (2017) |

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