VKM Report 2019: 15

# Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture

**Opinion of the Panel on Alien Organisms and Trade in Endangered Species of the Norwegian Scientific Committee for Food and Environment**

Report from the Norwegian Scientific Committee for Food and Environment (VKM) 2019: 15
Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture.

Opinion of the Panel on Alien Organisms and Trade in Endangered Species (CITES) of the Norwegian Scientific Committee for Food and Environment.
27.09.2019

ISBN: 978-82-8259-330-4
ISSN: 2535-4019
Norwegian Scientific Committee for Food and Environment (VKM)
Po 4404 Nydalen
N – 0403 Oslo
Norway

Phone: +47 21 62 28 00
Email: vkm@vkm.no

vkm.no
vkm.no/english

Cover photo: iStock

Suggested citation: VKM, Eli Rueness, Paul R. Berg, Snorre Gulla, Kim Halvorsen, Johanna Järnegren, Martin Malmstrøm, Tor Atle Mo, Espen Rimstad, Hugo de Boer, Katrine Eldegard, Kjetil Hindar, Lars Robert Hole, Kyrre Kausrud, Lawrence Kirkendall, Inger Måren, Erlend B. Nilsen, Eva B. Thorstad, Anders Nielsen and Gaute Velle (2019) Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture. Opinion of the Panel on Alien Organisms and Trade in Endangered Species (CITES) of the Norwegian Scientific Committee for Food and Environment. VKM report 2019: 15, ISBN: 978-82-8259-330-4, ISSN: 2535-4019. Norwegian Scientific Committee for Food and Environment (VKM), Oslo, Norway.

**Assessment of the risk to Norwegian biodiversity from import of wrasses and other cleaner fish for use in aquaculture.**

## Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) has appointed a project group consisting of four VKM members and four external experts to answer the request from the Norwegian Environment Agency. Two external referees commented on and reviewed the opinion.

## Authors of the opinion

Members of the project group that contributed to the drafting of the opinion (in alphabetical order after chair of the project group):

Eli Rueness – Chair of the project group and member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo.

Paul R. Berg – Member of the project group. Affiliation: 1) Department of Natural Sciences, University of Agder (UiA); 2) Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo.

Snorre Gulla – Member of the project group. Affiliation: The Norwegian Veterinary Institute (NVI), Oslo.

Kim Halvorsen – Member of the project group. Affiliation: Institute of Marine Research (IMR), Bergen.

Johanna Järnegren – Member of the project group and member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Martin Malmstrøm – Member of the project group and project leader in the VKM secretariat. Affiliation: VKM.

Tor Atle Mo – Member of the project group. Affiliation: Norwegian Institute for Nature Research (NINA), Trondheim.

Espen Rimstad – Member of the project group and member of the Panel on Animal Health and Welfare in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences (NMBU), Ås.

The opinion has been assessed and approved by the Panel on Alien Organisms and Trade in Endangered Species (CITES). Members of the panel that contributed to the assessment and approval of the opinion (in alphabetical order before chair/vice-chair of the Panel):

Hugo de Boer – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Natural History Museum, Oslo.

Katrine Eldegard – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian University of Life Sciences (NMBU), Ås.

Kjetil Hindar – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Lars Robert Hole – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) The Norwegian Meteorological Institute, Bergen.

Kyrre Kausrud – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) The Norwegian Veterinary Institute (NVI), Oslo.

Lawrence Kirkendall – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Department of Biology, University of Bergen.

Inger Måren – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Department of Biology, University of Bergen.

Anders Nielsen – Vice chair of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo.

Erlend B. Nilsen – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Eva B. Thorstad – Member of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Institute for Nature Research (NINA), Trondheim.

Gaute Velle – Chair of the Panel on Alien Organisms and Trade in Endangered Species (CITES) in VKM. Affiliation: 1) VKM; 2) Norwegian Research Centre AS (NORCE); 3) Department of Biology, University of Bergen.

## Acknowledgments

VKM would like to thank the referees Professor Niels Jørgen Olesen (Unit for Fish and Shellfish Diseases, Technical University of Denmark) and Professor Carl André (Tjärnö Marine Laboratory, University of Gothenburg) for reviewing and commenting on the manuscript. We also thank Dr. Daniel Flø (VKM secretariat) for help on graphical presentation of data.

## Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply for all work prepared by VKM.

# Table of Contents

# Summary

**Key words**: VKM, Risk assessment, Norwegian Scientific Committee for Food and Environment, Norwegian Environment Agency

**Introduction:**

The Norwegian Environment Agency requested the Norwegian Scientific Committee for Food and Environment to assess of the risk to Norwegian biodiversity from the import of wrasses and other cleaner fish for use in aquaculture.

Use of cleaner fish that prey on sea lice in Norwegian salmonid farms has increased substantially over the last decade and has led to a demand for import of cleaner fish from other countries.

Sea lice are small crustaceans parasitizing marine fish. They cause disease outbreaks and fish-welfare issues in Norwegian aquaculture and are a threat to wild salmonids. Two species, *Lepeophtheirus salmonis* and *Caligus elongatus*, are kept under control. The former, commonly called salmon louse, feeds on the marine stage of salmonids, whereas the latter has several hosts with a preference for lumpfish (*Cyclopterus lumpus*; rognkjeks). Numerous preventive medical and non-medical measures are applied to to control the parasite density in salmon farms (the requirement is <0.5 adult female lice per fish).

Ballan wrasse (*Labrus bergylta*; berggylt), goldsinny wrasse (*Ctenolabrus rupestris*; bergnebb), corkwing wrasse (*Symphodus melops*; grønngylt) and lumpfish (*Cyclopterus lumpus*; rognkjeks) are commonly used cleaner fish that are native to Norway

The use of Norwegian wild-sourced cleaner fish has been shown to alter genetic structure in the natural wrasse populations, when transported across population barriers, and may spread diseases. The likelihood of similar consequences could be even larger when introducing imported cleaner fish.

In 2017 and 2018, ~600,000 and ~800,000 wrasses, respectively, were imported from Sweden and transferred to aquaculture facilities along the Norwegian coast. For 2019, permission for import of wrasses has been granted for Sweden and Denmark by the Norwegian Environmental Agency. Goldsinny wrasse and corkwing wrasse have been imported in the largest numbers. Ballan wrasse is considered the best performing cleaner fish and is more expensive (33 NOK per individual vs 13.75 NOK for the other species as of 2018).

All cleaner-fish species imported to Norway are already traded within Norway. Until 2016, most cleaner-fish were wild-caught wrasses. However, production of cultured lumpfish has increased strongly in the last three years and surpassed the number of wrasses

combined in 2017. Aquaculture of wrasses and lumpfish is continuously developing, but is still entirely reliant on wild caught broodstock. Rearing of wrasses requires live feed and has proven to be more challenging than rearing of lumpfish.

Internationally, cleaner fish are used in Canada, Chile, the Faroe Islands, Iceland, Ireland, and the UK. Import of cleaner fish to Norway from these countries has not yet been applied for.

This report describes the general biology, distribution, and our current knowledge of the genetic population structure for each of the relevant cleaner-fish species.

VKM has assessed the risk from import of cleaner fish to biodiversity in Norway in terms of genetic change of local populations resulting from interbreeding with imported cleaner fish. The project group also assessed the risk from import for the spread of the species beyond their natural ranges, the risk from transferring pathogens and parasites among areas, and the risk from other ecological effects caused by imported cleaner fish. The possible spread of pathogen algae and fungi with cleaner fish was not assessed due to lack of information. The risk of genetic change was assessed in a 50-year perspective.

VKM proposes several measures that should be considered in order to reduce the risk of negative impacts from imported cleaner fish.

**Methods:**

VKM established a project group comprising different fields of expertise, including marine biology, ecology, bacteriology, virology, parasitology, and population genetics, to assess the likelihood of, and impact from, use of imported cleaner fish in Norwegian fish farms. The group reviewed relevant literature and conducted a semi-quantitative risk assessment. Potential hazards with respect to negative impacts on biodiversity were also evaluated.

The risk of genetic change of local populations and spread beyond their natural range were assessed for each cleaner-fish species individually. The risk of spread of parasites, bacteria and viruses was assessed for the three species of wrasses together, and for lumpfish separately. The risk of other ecological effects, and for negative effects in a 50-year perspective, were assessed for all species combined.

**Results:**

The amount of genetic change in native populations of cleaner fish will depend on the following factors:

1. The genetic differences between imported and native cleaner fish.
2. The age of sexual maturity in relation to age at import.
3. The number of fertilized eggs produced by imported fish in-cage.
4. The number of imported fish escaping, surviving, and successfully spawning.
5. The effective and census population size of the native cleaner-fish populations.

6. The survival/fitness of hybrid offspring.

From a 50-year perspective, with cleaner fish escaping over consecutive years, the genetic effects are expected to accumulate with time and with increasing numbers of imported cleaner fish. Climate change can be expected to influence the northern distribution limit of the species, the timing of spawning, and the composition of the ecosystem (e.g. the food web network and the presence of infectious agents).

For wrasses, the gill parasite *Microcotyle donavini*, and the flatworms *Macvicaria alacris*, and *Gaevskayatrema perezi* were identified as being of special concern, while no parasites were assessed as being relevant to include in relation to import of lumpfish.

Of the viral pathogens, nodavirus (nervous necrosis virus, NNV), viral haemorrhagic septicaemia virus (VHSV), and salmonid alphavirus (SAV) were identified to be of special interest regarding import of wrasses. In addition to lumpfish ranavirus, VHSV could be of concern regarding import of lumpfish.

Of the bacterial pathogens, only *Aeromonas salmonicida* is considered to pose a risk due to the geographic limits set by the import areas currently relevant for wrasses. *Pasteurella skyensis* / *Pasteurella* sp. and *Piscirickettsia salmonis* give reason for concern with regards to their potential import with lumpfish.

The project group has assessed that introducing alien organisms through bycatch when sourcing wrasses for use as cleaner fish in aquaculture and via cleaner fish transport water is a potential hazard. This has been exemplified by the spread of the round goby ("svartmunnet kutling") and pacific oyster ("stillehavsøsters").

**Discussion:**

The risks that imported cleaner fish may pose to Norwegian biodiversity will generally be influenced by the following factors:

1. **The amount of cleaner fish imported**, as both the escape rate and the probability of spreading infectious agents are expected to increase with the number of imported fish.
2. **The geographic origin of the imported fish** (as compared with the destination), as the risk of genetic change and introduction of novel pathogens will generally increase when the distance between local populations and imported fish increases. The origin is also relevant for the risk of spreading species beyond their natural ranges.
3. **The conditions of transport and handling prior to release** in the pen are important regarding the risk of disease transmission and spread of associated organisms (bycatch or transport water).
4. **The timing of import** will be important regarding the risk of genetic changes should the import take place prior to or during spawning.

5. **The extent of import over time** will be important regarding all the risks to biodiversity that were assessed, but particularly regarding the risk of genetic changes, which may accumulate over time.

**Conclusions:**

VKM has assessed that genetic change caused by crossbreeding with imported cleaner fish could have severe negative impact on local populations of corkwing wrasse and ballan wrasse and may also lead to reduction in viability and adaptability of native populations of goldsinny wrasse and lumpfish. Genetic change of local populations can persist and accumulate over time and the risk of negative consequences associated with current use of imported cleaner fish is therefore relevant in a 50-year perspective although the magnitude of the impact is unpredictable. The overall risk in terms of genetic change is assessed to be moderate for all four species.

The risk of negative impact from the spread of the species beyond their natural ranges was assessed to be moderate for corkwing wrasse and low for the three other species of cleaner fish.

There are considerable knowledge gaps considering infectious agents in the cleaner-fish species, but it was assessed that the gill parasite *Microcotyle donavini,* if transferred from imported fish, might have a moderate negative impact on viability of the local populations of wrasses. Further that the *Viral haemorrhagic septicaemia virus* (VHSV) could have severe negative impact to any of the cleaner fish if spread.

The project group assessed that the risk of negative impacts on biodiversity in Norway following introduction of alien species through by-catch or transport water to be moderate.

Overall, VKM concludes that the use of imported cleaner fish poses a moderate risk for negative impacts on biodiversity in Norway.

# Sammendrag på norsk

I løpet av de siste ti årene har bruken av rensefisk til bekjempelse av lakselus i norske oppdrettsanlegg for laksefisk økt voldsomt, og det har derfor blitt nødvendig å importere rensefisk fra andre land. Miljødirektoratet har bedt Vitenskapskomiteen for mat og miljø om å vurdere hvilken risiko import av gylter og andre rensefisk brukt i norske oppdrettsanlegg utgjør for biologisk mangfold.

**Bakgrunn**

Lakselus (*Lepeophtheirus salmonis*) og skottelus (*Caligus elongates*) er små parasittiske krepsdyr. De har forårsaket sykdomsutbrudd i fiskeoppdrett langs norskekysten, og anses derfor som en trussel for villaksen. Lakselus angriper laksefisk, mens skottelusen, som kan angripe mange arter, foretrekker rognkjeks (*Cyclopterus lumpus*). I norske oppdrettsanlegg er det et krav at antall lus ikke skal overstige 0,5 voksen hunnlus per fisk. Det benyttes mange forebyggende tiltak for å nå dette kravet, både medisinske og ikke-medisinske.

I Norge benyttes hovedsakelig rognkjeks (*Cyclopterus lumpus*) og tre gyltearter av som rensefisk: berggylt (*Labrus bergylta*), bergnebb (*Ctenolabrus rupestris*) og grønngylt (*Symphodus melops*. Alle disse artene finnes naturlig i Norge.

I 2017 og 2018 ble det satt ut henholdsvis 600 000 og 800 000 rensefisk, importert fra Sverige, i norske oppdrettsanlegg for laksefisk. For 2019 har Miljødirektoratet utstedt tillatelser til å importere leppefisk fra Sverige og Danmark. Hittil har det blitt importert mest bergnebb og grønngylt. Berggylt er ansett som den mest effektive rensefisken, men er godt over dobbelt så dyr (32 NOK mot 13,75 NOK i 2018).

Alle arter som importeres for bruk finnes naturlig og omsettes innad i Norge. Frem til 2016 bestod markedet nesten utelukkende av villfangete gylter, men siden 2017 har omsetningen av oppdrettet rognfisk overgått salget av gylter. Det er stadig utvikling innen oppdrett av både rognkjeks og gylter, men foreløpig er oppdrettsbransjen fullstendig avhengig av villfanget rensefisk.

Internasjonalt brukes rensefisk i oppdrett i følgende land: Canada, Chile, Færøyene, Irland, Island og Storbritannia. Det har foreløpig ikke vært aktuelt å importere rensefisk fra noen av disse landene.

Rapporten beskriver biologi, utbredelse og det man vet om genetisk struktur for hver av de fire artene som i dag brukes mest som rensefisk i Norge.

VKM har vurdert risikoen for at det kan oppstå genetiske endringer i lokale bestander dersom de parer seg med rømt importert rensefisk. Det er videre vurdert hvorvidt import øker risikoen for at rensefisk sprer seg utover sitt naturlige utbredelsesområde.

Sykdom er blant de viktigste dødsårsakene i norske oppdrettsanlegg og prosjektgruppen har vurdert en rekke parasitter, bakterier og virus med potensiale for å spres til gylter og rognkjeks. Muligheten for spredning av sykdomsfremkallende alger og sopp med importert rensefisk er ikke vurdert, på grunn av manglende data, Prosjektgruppen har vurdert risikoen for negative økologiske effekter forårsaket av spredning av fremmede organismer, enten som bifangst eller med transportvannet når rensefisk importeres. Siden genetiske endringer kan bestå over generasjoner, er risikoen for genetiske endringer vurdert i et perspektiv på 50 år.

VKM har vurdert en rekke tiltak som kan redusere risikoen for negative konsekvenser ved bruk av importert rensefisk.

**Metode:**

VKM opprettet en prosjektgruppe bestående av eksperter som representerer ulike fagområder inkludert marinbiologi, økologi, bakteriologi, virologi, parasittologi og populasjonsgenetikk. Gruppen har vurdert relevant litteratur og gjennomført en semi-kvantitativ risikovurdering.

Gruppen evaluerte relevante negative effekter på norsk biologisk mangfold.

Risikoen for genetiske endringer og spredning av arter utenfor det naturlige utbredelsesområdet, ble vurdert for hver art separat. Risikoen for spredning av smittestoffer fra parasitter, bakterier og virus ble vurdert for gyltene sammen og rognkjeks for seg. Risikoen for andre økologiske effekter og for negative effekter i et 50-års perspektiv, ble gjort for alle artene samlet.

**Resultater:**

Risikoen for negativ genetisk endring i lokale bestander av importert rensefisk vil avhenge av følgende faktorer:

1) Hvor ulik genetisk den importerte fisken er i forhold til de lokale bestandene.
2) Alder under import i forhold til reproduktiv alder.
3) Mengden av egg som de importerte fiskene produserer i merden.
4) Antallet importert fisk som rømmer og deretter formerer seg.
5) Populasjonsstørrelsen av de lokale bestandene.
6) Overlevelse- og reproduksjonsevne til avkom av importert fisk.

I et 50-års perspektiv med årlig rømning av importert rensefisk forventes det at de genetiske endringene i lokale bestander vil akkumuleres over tid og med antall importert fisk. Klimaendringer forventes å påvirke den nordlige grensen av artenes utbredelse, gytetidspunkt og økosystemenes sammensetning, blant annet hvilke smittestoffer som vil være tilstede.

For gyltene ble gjelleparasitten *Microcotyle donavini* og iktene (trematoder) *Macvicaria alacris* og *Gaevskayatrema perezi* vurdert som potensielt problematiske, mens ingen parasitter ble risikovurdert for rognkjeks.

Av virus ble Nodavirus (Nervous necrosis virus), Viral haemorrhagic septicaemia virus (VHSV) og Salmonid alphavirus (SAV) vurdert som en potensiell risiko for gyltene, mens lumpfish ranavirus i tillegg til VHSV ble utpekt som risikable for rognkjeks.

Av virus ble av geografiske grunner kun *Aeromonas salmonicida* ansett som en trussel mot gylter, mens *Pasteurella skyensis / Pasteurella* sp. og *Piscirickettsia salmonis* ble vurdert for rognkjeks.

VKM har kommet frem til at både bifangst og transportvann kan føre til spredning av organismer som kan ha uheldige effekter på miljøet, noe som er eksemplifisert ved spredning av svartmunnet kutling og stillehavsøsters.

**Diskusjon:**

Risikoen for negative effekter av importert rensefisk på norsk biologisk mangfold vil generelt avhenge av følgende faktorer:

1) **Mengden av importert fisk**, siden både rømningsrate og sannsynligheten for å spre smittestoffer forventes å øke med antall fisk satt ut.
2) **Den geografiske opprinnelsen** av den importerte fisken (i forhold til destinasjon) siden risiko for genetiske endringer, spredning utover naturlig utbredelsesområde og introduksjon av nye smittestoffer øker med økt avstand mellom importert fisk og lokale bestander.
3) **Forhold under transport og oppbevaring før utsetting i merder** er viktig for smitte og spredning av følgeorganismer fra bifangst eller transportvann.
4) **Tidspunkt for utsettelse** er avgjørende for risiko for genetiske endringer hvis innførsel skjer før eller under gyting.
5) **Omfang av import over tid** vil være avgjørende for alle vurderte effekter på biologisk mangfold, spesielt for genetiske endringer i et 50-års perspektiv.

**Konklusjoner:**

VKM har vurdert at genetiske endringer forårsaket av krysning med importert rensefisk kan ha betydelig negativ innvirkning på lokale bestander av grønngylt og berggylt. Krysning med importert rensefisk kan også føre til redusert overlevelses- og tilpasningsevne hos bestander av rognnebb og rognkjeks. Genetiske endringer kan bestå og akkumuleres i bestander over tid. Bruk av importert rensefisk nå kan derfor være avgjørende for risikoen for negative konsekvenser i et 50-års perspektiv, selv om graden av negativ innvirkning er uforutsigbar. Alt i alt ble risikoen for genetiske endringer vurdert til å være moderat for alle de fire artene.

Risikoen for negative effekter ved spredning av arter utenfor sitt naturlige utbredelsesområde ble vurdert til moderat for grønngylt og lav for de tre andre artene.

Det er betydelige kunnskapshull når det gjelder smittestoffer i rensefiskartene, men det ble vurdert at gjelleparasitten *Microcotyle donavini* kan ha moderat negative innvirkning på overlevelsen til lokale gyltebestander hvis den overføres fra importer rensefisk. Videre kan *Viral haemorrhagic septicaemia virus* (VHSV) ha alvorlige negative påvirkninger på alle de viltlevende rensefiskartene, hvis det spres.

Prosjektgruppen vurderte risikoen for at fremmede organismer som innføres sammen med importert rensefisk som bifangst eller med transportvann, skal få negative effekter på norsk biologisk mangfold til å være moderat.

Samlet sett konkluderer VKM med at bruk av importer rensefisk utgjør en moderat risiko for negativ påvirkning på biologisk mangfold i Norge.

# Abbreviations and acronyms

| | |
|---|---|
| CLuV | *Cyclopterus lumpus* virus |
| CMS | Cardiomyopathy syndrome |
| Ct | Cycle threshold |
| EFSA | The European Food Safety Authority |
| EHNV | Epizootic haematopoietic necrosis virus |
| $F_{ST}$ | Fixation index |
| IBD | Isolation-by-distance |
| i.p. | Intraperitoneal |
| IPCC | The Intergovernmental Panel on Climate Change |
| IPNV | Infectious pancreatic necrosis virus |
| ISAV | Infectious salmon anaemia virus |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| NOK | Norwegian kroner |
| NNV | Nervous necrosis virus |
| OIE | World Organisation for Animal Health (Office International des Epizooties) |
| PCR | Polymerase chain reaction |
| PD | Pancreas disease |
| PLH | Panel on Plant Health |
| PMCV | Piscine myocarditis virus |
| PRV | Piscine orthoreovirus |
| qPCR | Quantitative PCR |
| RCP | Representative concentration pathway |
| RT-qPCR | Reverse transcription qPCR |

| | |
|---|---|
| SAV | Salmonid alphavirus |
| SNP | Single-nucleotide polymorphism |
| VHSV | Viral haemorrhagic septicaemia virus |
| Wpc | Weeks post challenge |

# Background as provided by the Norwegian Environment Agency

The Norwegian Environment Agency refers to the direct debit mandate for assignments to the Norwegian Scientific Committee for Food and Environment (VKM) concerning risk assessments in 2018 and hereby requests that VKM conducts an assessment of the environmental risk of importing wrasses for use as cleaner fish in the fish farming industry.

**Background**

Corkwing wrasse, ballan wrasse and goldsinny wrasse are species of wrasse that naturally occur along the Norwegian coastline. These species are used in salmon farming to combat sea lice. They are primarily found from the Mediterranean Sea and North Africa to the Trondheim Fjord in Norway, though some swim as far north as Lofoten.

The Regulations relating to alien organisms under the Norwegian Nature Diversity Act, which entered into force on 1 January 2016, establishes the requirement to hold a permit for import and release of species of wrasse. The Norwegian Environment Agency processes applications concerning import to Norway.

As a basis for processing of applications, the Norwegian Environment Agency requires a scientific assessment of the risk of adverse impacts on biodiversity concerning import and release of species of wrasse in Norway.

**Legal background:**

The purpose of the Regulations of 19 June 2015 no. 716 relating to alien organisms (the Regulations) is to prevent the import, release and spread of alien organisms that have or may have adverse impacts on biological or landscape diversity., cf. the Regulations Section 1.

Pursuant to Section 6, a permit is required for the import of wrasses, hereunder the species corkwing wrasse, ballan wrasse and goldsinny wrasse. These species are neither covered by the prohibition against import in Section 5, nor by the exceptions from the requirement to hold an import permit in Section 2 or Section 7. The Norwegian Environment Agency may, upon processing an application, grant an import permit. The release of cleaner fish in aquaculture does not require a permit under the Regulations, cf. Section 11, first paragraph (h).

The Norwegian Environment Agency may, upon processing an application, grant an import permit for the organisms to which the application applies. The principles in the Norwegian Nature Diversity Act Sections 8 to 12 serve as guidelines for the assessment, cf. the Norwegian Nature Diversity Act Section 7. Other important public interests shall also be considered in the assessment, cf. the Norwegian Nature Diversity Act Section 14. A permit may not be granted if there is reason to believe that the import or release will have substantial adverse impacts on biodiversity, cf. the Regulations Section 15, third paragraph. Assessments regarding the granting of permits under the Regulations shall not include considerations relating to plant, animal and human life and health that are safeguarded by the Norwegian Communicable Diseases Control Act and the Norwegian Food Act, cf. the Norwegian Nature Diversity Act, Section 32, third paragraph. The Norwegian Environment Agency shall assess and lay down any conditions that are considered necessary to prevent adverse impacts on biodiversity, cf. the Regulations Section 15, fourth paragraph.

**Conditions:**

The risk assessment report shall be written in English with a summary in Norwegian. The report is published in dialogue with the Norwegian Environment Agency. Reference is otherwise made to the collaboration agreement between the Norwegian Environment Agency and VKM.

The time limit for the submission of the report is 1 October 2019.

# Terms of reference as provided by the Norwegian Environment Agency

The Norwegian Environment Agency requests the Norwegian Scientific Committee for Food and Environment to:

1. Identify species relevant for import for use as cleaner fish in aquaculture, and the relevant areas (countries) of source-populations for these species.

2. Identify potential hazards associated with import of the relevant species, including:
   a) Genetic change of local populations
   b) Spread of species beyond the natural range
   c) Transfer of pathogens and parasites between areas
   d) Other ecological effects

3. Assess the consequences of:
   a) Genetic change of local populations
   b) Spread of species beyond its natural range
   c) Transfer of pathogens and parasites between areas
   d) Other ecological effects (identified under ToR 2d)

4. Assess the likelihood of:
   a) Genetic change of local populations
   b) Spread of species beyond the natural range
   c) Transfer of pathogens and parasites between areas
   d) Other ecological effects (identified under ToR 2d)

5. Characterize the risk of:
   a) Genetic change of local populations
   b) Spread of species beyond the natural range
   c) Transfer of pathogens and parasites between areas
   d) Other ecological effects (identified under ToR 2d)

6. Summarize the information needed to make a qualified judgement call on whether import could have a negative impact or not.

If there are special measures or restrictions that will affect the risk, this must be stated in the assessment.

If the import of species of wrasse may impact ecosystem services, this shall also be stated in the report but shall not be included as part of the assessment of risk of adverse impacts on biodiversity.

# 1 Introduction

## 1.1 Clarifications pertaining to the terms of reference

In order to answer the Terms of Reference, the project group added the following clarifications:

- The effects of imported cleaner fish on biodiversity in Norway is limited to effects on native cleaner-fish species and ecosystem interactions involving these species, provided that such interactions can be documented.
- This report does not characterise the risks that cleaner-fish import may pose to farmed salmonids, as this matter is covered in a previous report (VKM 2017).
- Animal health and welfare during the transport and use of imported cleaner fish are not addressed in this assessment.
- This report is not a comprehensive evaluation of the effects of translocation of cleaner fish within Norway, nor of the effects on the harvested populations.
- The possible genetic and ecological effects from use of imported cleaner fish are considered in a 50-year perspective.

## 1.2 Sea lice in Norwegian salmonid aquaculture

Sea lice are copepods that are ectoparasites (external parasites) feeding on the skin of marine fish. Sea lice have both planktonic (free floating) and parasitic life stages and cause physical damage and increased stress to their host species. Sea-lice larvae are generally found in the first few metres of water below the surface.

### 1.2.1 *Lepeophtheirus salmonis*

The salmon louse, *Lepeophtheirus salmonis*, is a specialized parasitic copepod found on salmonids in their marine life stage only. Salmon lice have caused disease outbreaks and fish-welfare issues since the beginning of aquaculture in Norwegian coastal areas, and the release of salmon-lice larvae from aquaculture is considered a threat to wild salmonids. Thus, numerous preventive medical and non-medical measures are used to keep the densities of salmon lice at low levels (< 0.2 - 0.5 adult female lice per salmon, depending on the time of year).

### 1.2.2 *Caligus elongatus*

*Caligus elongatus* is a generalist parasitic copepod found on more than 80 species of marine fish. It has been present in Norwegian aquaculture since the beginning of salmon farming, but, compared with salmon lice caused minor challenges and damages. However, in the last decade or so, *C. elongatus* has increasingly become a plague to farmed salmonids, especially in the northernmost counties of Norway. The explanation for this temporal trend and regional distribution could be higher occurrences of this parasite on wild fish in this area or increasing use of lumpfish (*Cyclopterus lumpus*) as a cleaner fish. Lumpfish is the preferred host for *C. elongatus*.

### 1.2.3 Problems/Costs

Efficient sea-lice control remains one of the most important challenges in farming of Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*). Sea lice cause direct problems for the farmed fish and can also transmit infectious organisms, such as viruses, bacteria, and protists. The estimated costs and losses caused by sea lice in 2018 were estimated to be 5–6 billon NOK (DN 2018).

## 1.3 Measures taken to control sea lice in Norwegian salmonid aquaculture

In order to improve fish health and welfare and to reduce losses, different measures are used to reduce the density sea lice in salmonid aquaculture. These can be divided into three categories: preventive measures, medical measures, and non-medical measures.

### 1.3.1 Preventive measures

Physical measures that are intended to prevent the louse larvae from infesting the fish host include the use of tarpaulin skirts around the cages and use of submerged cages with tubes, air bubbles, and light. Another approach is use of specialized feed that is designed to improve the mucus layer of the fish and thereby reduce attachment of sea lice. Furthermore, through selective breeding, the salmon produced today has become more resistant. Recently, lice-larvae traps with kairomones (attractants) and lights, as well as filtering of large water volumes in the cages, have been tested, but proof of concept is still lacking. Effective vaccines against sea lice have not yet been developed.

### 1.3.2 Medical measures

Medical treatments are either administered in feed or as a bath treatment in the cage or in a well-boat. Several drugs are used. In many coastal areas, sea lice have developed reduced sensitivity (resistance) to most of these drugs. In some areas, the chemicals used are not sufficiently effective to keep the lice at the levels required by the authorities (see 1.2.1). Drug use in sea-louse control has thus been reduced in recent years, while the use of non-medical treatments has increased.

### 1.3.3 Non-medical measures

The most commonly used methods are detailed below.

#### *1.3.3.1 Chemical treatment*

Hydrogen peroxide ($H_2O_2$) will temporarily paralyse sea lice and thus prevent their attachment to salmon. By volume, it is the most-used chemical treatment in Norwegian fish farms. Either hydrogen peroxide is added to the cages covered by a tarpaulin or the fish in the cages are pumped into a well-boat and treated there.

#### *1.3.3.2 Thermal delousing*

In thermal delousing, the fish are pumped through a curved tube containing lukewarm seawater (28-34 °C) for about 30 seconds. The treatment is efficient but is associated with fish-welfare challenges and occasionally causes fish mortality.

#### *1.3.3.3 Freshwater treatment*

Freshwater has commonly been used as a treatment against sea lice but is not considered sufficiently effective and the large volumes needed are a challenge. It is also a concern that sea lice may develop reduced sensitivity to freshwater after repeated treatments. Furthermore, although salmonids are freshwater tolerant, cleaner fish are sensitive to the lowered salinity and the treatment therefore reduces their welfare.

#### *1.3.3.4 Mechanical removal*

Mechanical delousing has become increasingly common in recent years and includes several methods. Laser technology individually kills sea lice attached to the fish, while brushing or spraying with seawater is used to remove sea lice from the fish when pumped through a tube. The fish are treated with seawater at low pressure (<1 bar) for a few seconds. However, these methods have resulted in significant skin damage and are associated with severe fish-welfare challenges.

#### *1.3.3.5 Cleaner fish*

Several wrasse species and lumpfish are used as cleaner fish in Norwegian aquaculture. The cleaner fish graze on adult and pre-adult stages of sea lice that are attached to farmed salmonids. The use of cleaner fish is gentle to the salmonids, but serious issues regarding the welfare of the cleaner fish have recently been raised (Mortensen et al. 2018, Mo and Poppe 2019). Moreover, using wild-sourced cleaner fish has been shown to reduce the numbers and alter the genetic structure of natural wrasse populations (Halvorsen 2016b, Halvorsen et al. 2017a, Faust et al. 2018), and may introduce diseases (Korsnes et al. 2017). Although most lumpfish used as cleaner fish are hatchery-reared, nearly all are derived from wild broodstock (Powell et al. 2018) and that might negatively affect the native populations. Lumpfish is classified as a “near-threatened species” on the IUCN Red List and their abundance has declined by 25-35% worldwide over the last few decades (Lorance et al. 2015).

## 1.4 The use of cleaner fish in aquaculture

### 1.4.1 Use of cleaner fish in Norway

The use of wild-caught wrasse as cleaner fish in salmon farming started in Norway in 1988 (Bjordal 1988). In the late 1990s, however, the practice diminished with the introduction of medicine coupled with detection of infectious salmon anaemia. A second phase of cleaner fish use began around 2008, also using species of wrasse, and commercial-scale breeding of wrasse also began. Three species of wrasses, goldsinny, ballan, and corkwing (see section 1.6 for thorough descriptions), are currently the main species used in Norwegian aquaculture. Research on using lumpfish as cleaner fish began in 2013 and their potential for being bred in large numbers was soon recognized. Generally, an advantage of using lumpfish is that they tolerate lower seawater temperatures than wrasses.

Until 2016, the majority of cleaner fish used in Norwegian aquaculture were wild-caught wrasse, but the production of farmed lumpfish increased greatly between 2015 and 2018, surpassing the number of combined wrasse species in 2017 (Figure 1.4.1 -1).

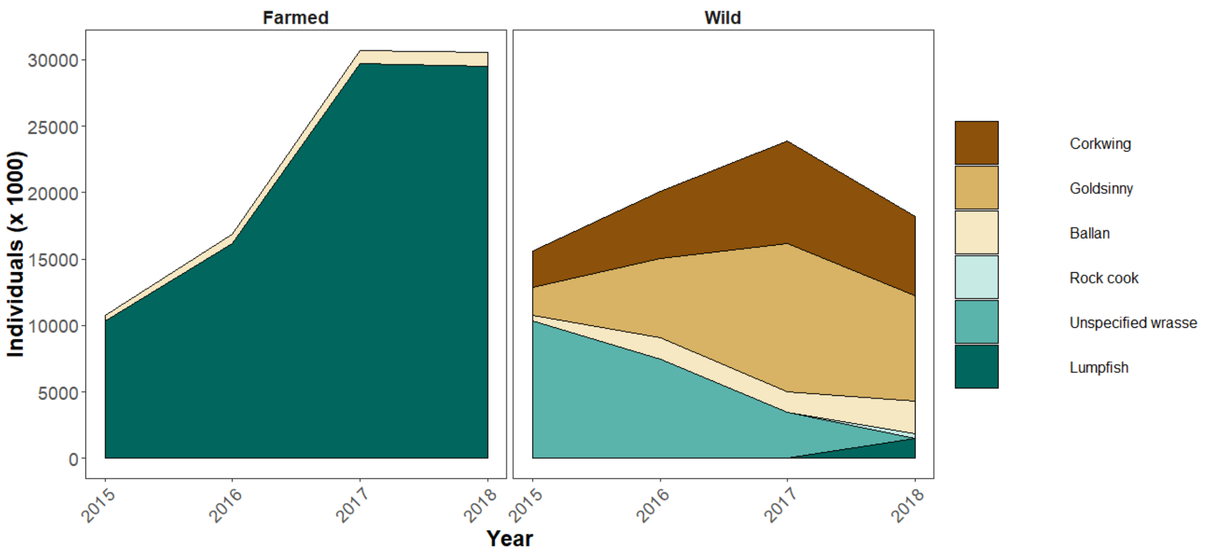


**Figure 1.4.1-1:** Numbers of cleaner fish used in Norwegian aquaculture 2015-2018. Data source: The Norwegian Directorate of Fisheries.

The ratio of cleaner fish to aqua cultured individuals in each pen depends on several fakorts, e.g. the species being farmed, the cleaner-species used, the salmon lice load, temperature and water currents. In salmon farms, the percentage of labrids-to salmon has varied between 0.5 and 4.1% in 2002-2010 (Skiftevik et.al. 2014). The guidance document from the industry quotes that some see good effects at 1%, while 3-5% is now normal.

### 1.4.2 Use of cleaner fish in Europe

#### *1.4.2.1 UK*

The predominant species of cleaner fish used in the UK (mainly Scotland) are lumpfish and ballan wrasse. In contrast to the use of lumpfish, the use of ballan wrasse is still heavily dependent on wild-caught supply. The capture fisheries can be roughly divided into one-third in Scotland and two-thirds in England (Riley et al. 2017).

#### *1.4.2.2 Ireland*

In Ireland, all three species of wrasses predominantly used in Norway are used as cleaner fish. All are wild caught, mainly during summer. During the winter months, farmed lumpfish are used (Balton-Warberg, 2018).

#### *1.4.2.3 Iceland*

In Iceland, the use of cleaner fish is still very limited, partly due to a relatively modest salmonid aquaculture industry and partly since sea lice are not considered a major problem (Karbowski et al. 2019). The low ambient seawater temperatures in the Icelandic fjords (4–5°C annual mean, 0–1°C in the winter) are considered by many to be a natural barrier to extensive sea-lice infestations. None of the wrasse species are native to Icelandic waters, but some lumpfish are used as cleaner fish. Iceland is a large producer of lumpfish for aquaculture and most are exported.

#### *1.4.2.4 Faroe Islands*

As in Iceland, only lumpfish are used in the Faroe Islands, due to low seawater temperatures and low levels of sea lice. All lumpfish used in Faroese aquaculture are currently imported from Iceland (Johannesen et al. 2018).

### 1.4.3 Use of cleaner fish in other countries

The use of cleaner fish in salmonid aquaculture outside Europe is still limited and under development. As the species used in Europe are not native to all countries with salmonid aquaculture, but various native species are currently being tested.

#### *1.4.3.1 Chile*

In Chile, the use of cleaner fished for de-lousing is under assessment. The dominant sea louse species found in salmon and trout farms in Chile is *Caligus rogercresseyi*, and is transmitted by native fish species (Gonzalez and Carvajal 2003). Trials conducted with a native fish, the Patagonian blenny (*Eleginops maclovinus*), have provided especially promising results, as this species can be successfully reared in captivity (Sánchez et al.

2018). The wrasse species *Malapterus reticulatus* and the grey mullet, *Mugli cephalus,* are also being assessed as potential cleaner fishes, but results have not yet been published (Sánchez et al. 2018). Sea lice have historically been controlled by medical measures in Chile, however the lice have now developed resistance to most of the medical substances (Augusti et al. 2016). There are no regulations regarding the use of cleaner fish in Chile (Sánchez et al. 2018).

#### *1.4.3.2 Canada*

None of the wrasse species used as cleaner fish in Europe are native to Atlantic Canada. Lumpfish, however, are distributed on both sides of the Atlantic. The cunner (*Tautogolabrus adspersus*), a wrasse species, is also being farmed, tested, and used as cleaner fish in Canada. The choice of cleaner species for a given region is based on the species' temperature requirements. The use of wild-caught cleaner fishes is not permitted for marine salmon cage sites in Canada (Boyce et al. 2018), hence they farm all cleaner fish.

Both Chile and Canada foresee an increasing use of cleaner fish in the future.

### 1.4.4 Sourcing of cleaner fish

When the use of cleaner fish first started in aquaculture, only wild-caught fish were available. Later, the increasing demand, caused largely by the sea lice's reduced sensitivity to medical treatments, led to an intensification in rearing of cleaner fish, mainly ballan wrasse and lumpfish. Ballan wrasse is considered the most efficient cleaner-fish species, and is also robust and with relatively high survival rates (Prickett 2016). However, at lower temperatures, lumpfish are more efficient and have higher survival rates.

#### *1.4.4.1 Rearing of cleaner fish*

Aquaculture of wrasses and lumpfish is in continuous development in order to improve the survival, growth, and general quality of the fish reared. However, the production of wrasses has not accelerated as fast as initially expected due to the time-consuming weaning and slow growth (Treasurer 2018). Farming of lumpfish is still at an early stage but appears as less problematic than that of wrasses. This is partly because lumpfish can be fed with commercial dry feed, whereas ballan wrasse initially require live feed (Sveier and Breck 2018). Moreover, the higher water temperatures required for rearing wrasses, compared with that required for lumpfish, makes production more expensive.

The higher success rate in lumpfish rearing is reflected by the marked increase in their production observed in recent years (Figure 1.4.1 -1). In 2016, 24 companies had 52 licenses to rear cleaner fish in Norway, with four of these used for ballan wrasse, and the rest for lumpfish (Sveier and Breck 2018).

All hatcheries for both ballan wrasse and lumpfish currently rely entirely on wild-caught broodstock. This causes numerous issues associated with the vulnerability to exploitation of wild fish. Thus, for both species, future commercial production should be completely derived from farmed strains that have been selected for high affinity for preying on sea lice (Powell et al. 2018).

### *1.4.4.2 Wild-caught cleaner fish*

Most wild-caught wrasses used in Norway are also sourced from Norway, and close to 18.5 million wrasses were landed in 2018 for use in aquaculture (Table 1.4.4.2-1). Figure 1.4.4.2-1 shows the numbers of wild wrasses landed in Norway in the years 2013-2018. Figures 1.4.4.2-2 and 1.4.4.2-3 show the number of wrasses imported from Sweden in 2017 and 2018 to aquaculture facilities south and north of Stadt. In Norway, fishing for wrasse is regulated through the Norwegian Directories of Fisheries (see section 1.4.5 for detailed information). The fish are caught in fish pots or 'fyke nets' (a fish trap), and there is a recommended maximum storage time of five days or straight delivery to the fish farm. In 2011, a general size limit of 11 cm was enforced for all species to reduce escapes from sea pens. Size limits are now species dependent (Table 1.4.4.2-1).

Table 1.4.4.2-1. An overview of the main management regulations that apply in Norway and Sweden regarding capture of wild wrasses for aquaculture, and recorded landings in 2018 by species. The landings in Sweden are mostly exported to Norway.

| | **Norway** | **Sweden** |
|---|---|---|
| **Opening date 2019** | July 17*(July 31) | May 15 |
| **Closing date 2019** | October 23 | October 31 |
| **Size limit: corkwing** | 12 cm | 13 cm |
| **Size limit: ballan** | 14 cm | 15 to 30 cm |
| **Size limit: goldsinny** | 11 cm | 11 cm |
| **2018 landings: corkwing** | 8 181 230 | 457 476 |
| **2018 landings: goldsinny** | 8 039 554 | 313 766 |
| **2018 landings: ballan** | 1 879 121 | 46 552 |
| **2018 landings: rockcook** | 394 239 | Not allowed |
| **2018 Total landings** | 18 494 144 | 817 794 |

*date in parenthesis is for North of Stadt.

To avoid bycatch of wrasses below the size limits, experiments with various gear modifications have been conducted (Jørgensen et al. 2017, Halvorsen et al. 2017b), and the use of escape panels with 12 mm grids is now compulsory in the Norwegian fisheries. In Norway, the fishery is closed until the spawning season is over in order to minimize disturbance to the reproduction of wrasses (Table 1.4.4.2-1). Regulations in Sweden differ slightly (Table 1.4.4.2-1). In Sweden escape panels are not compulsory, which implies that more undersized wrasses and smaller bycatch species will be caught and the catch will require manual sorting according to the size limits, which also differ between Norway and

Sweden (Table 1.4.4.2-1). The earlier opening date for fishery in Sweden also allows for catch, translocation, and release of wrasses that are ready to spawn. Although relatively few fish are imported during this period (see fig. Figure 1.4.4.2-2 and Figure 1.4.4.2-3), they can have strong impact on the genetic composition.

The practice of wrasse fishery has not been established in Denmark to date, despite Norwegian applications for import. Hence there are no restrictions on catching wrasses, but export is currently not allowed by the Danish food safety authorities (Peter Rask Møller, pers. comm.).

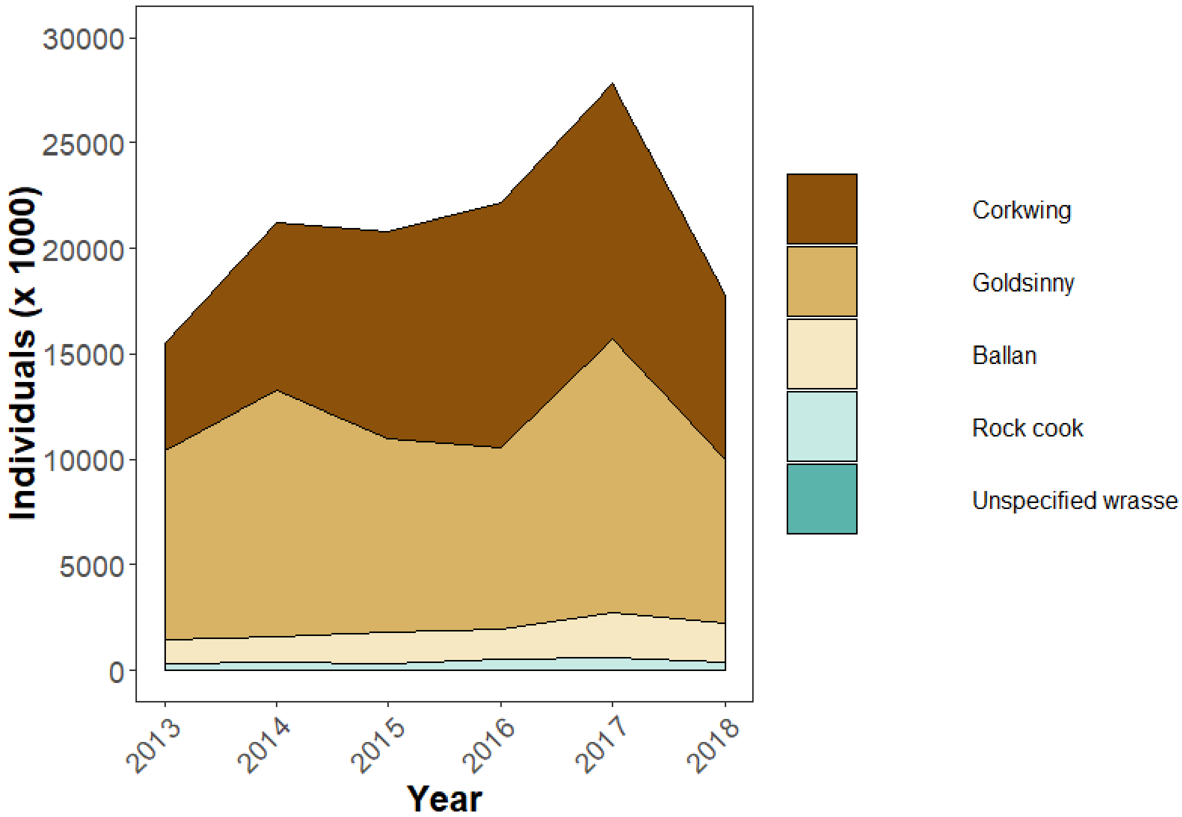


**Figure 1.4.4.2-1:** The development in Norwegian landings of wrasse species 2013-2018. Data source: The Norwegian Directorate of Fisheries

As in Norway, both fyke nets and pots are used in Sweden (Andersson 2019), but the proportion of fishermen using each type of gear is unknown. Fyke nets have a considerably higher proportion of bycatch species than pots (Halvorsen et al. 2017a,b).

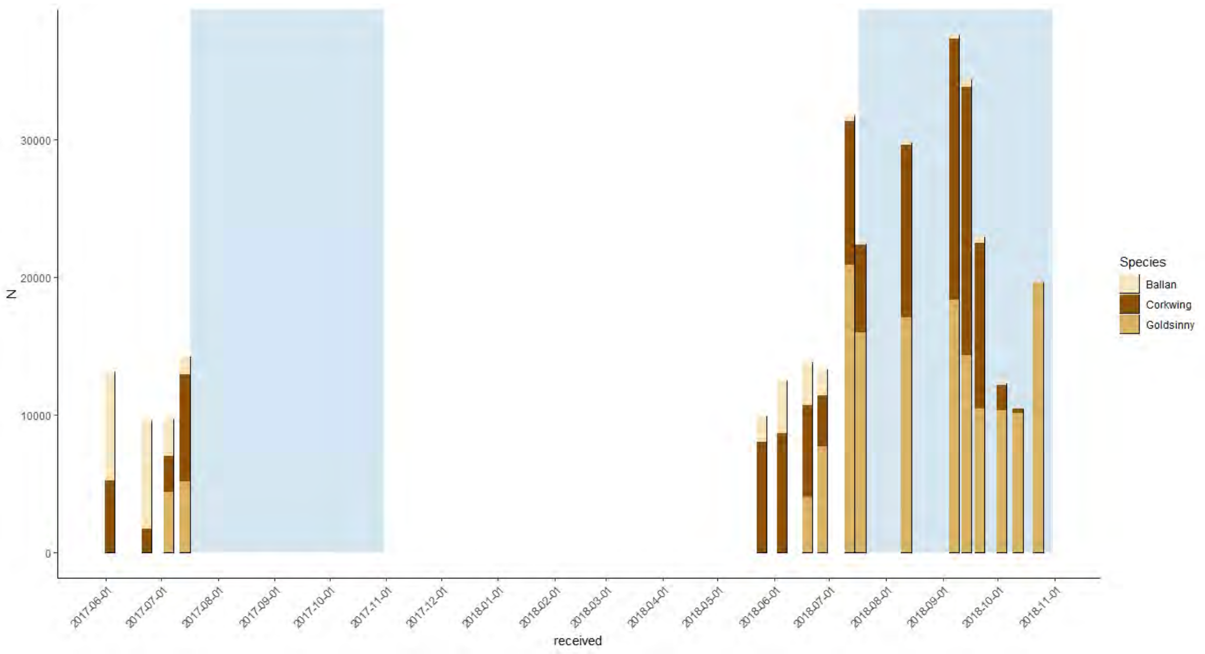


**Figure 1.4.4.2-2:** Number of imported wrasses sorted by date of arrival to Norway (south of Stadt / 62°N). Bars represent weekly import numbers for each species. Light blue shade illustrates when fishing is allowed in Norway in this area, and the beginning corresponds to the end of the main spawning season. See 2.4.2 for more information on the data.

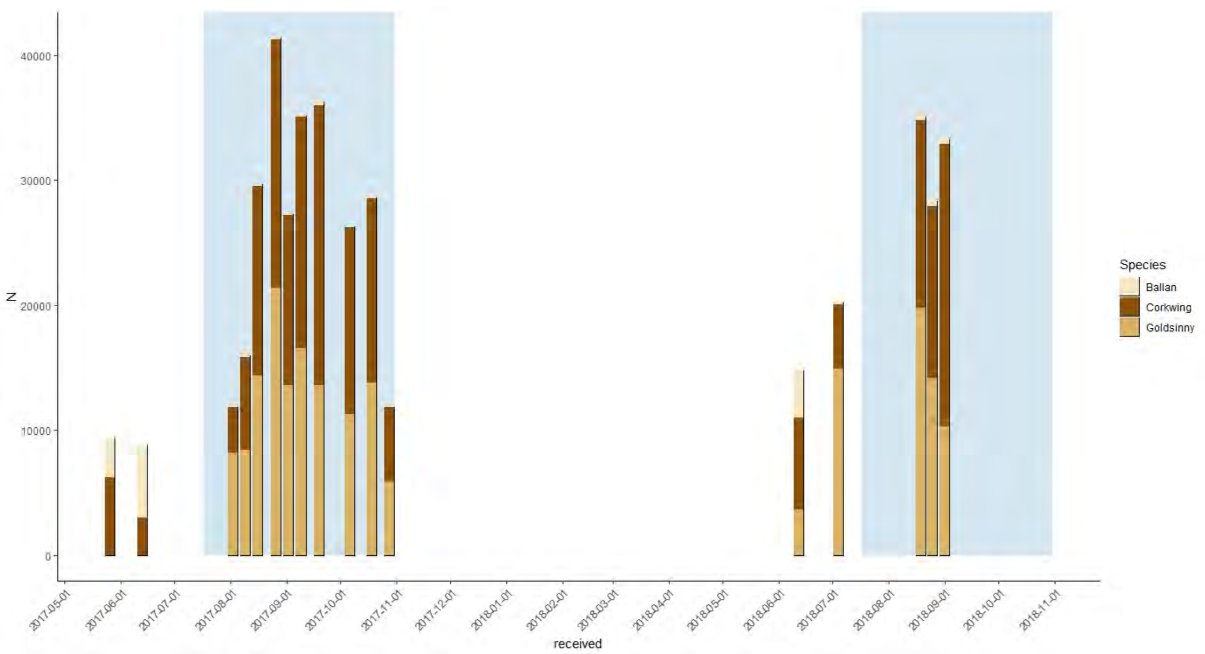


**Figure 1.4.4.2-3:** Number of imported wrasses sorted by date of arrival to Norway (north of Stadt / 62°N). Bars represent weekly import numbers for each species. Light blue shade illustrates when fishing is allowed in Norway in this area, and the beginning corresponds to the end of the main spawning season. See 2.4.2 for more information on the data.

### 1.4.5 Legislation regulating the catch and use of cleaner fish in Norway

For Norway, a total annual quota of 18 million wild-caught wrasse (all species) has been set by the Directorate of Fisheries for 2019. The annual quota is divided amongst three zones: From the border of Sweden to Vest-Agder (4 million), from Rogaland to Stadt / 62°N (10 million), and north of Stadt / 62°N (4 million). The total quota is also divided between 90% to a closed group (vessels that have caught wrasse previously, in addition to fulfilling regular requirements) and 10% to an open group (vessels that fulfil the regular requirements but have not previously caught wrasse). The number of fish per vessel is limited to 48,000 for vessels in the closed group and 5,000 for the open group.

A limit on the number of pots per vessel was set to 100 in the zone from the Swedish border to Agder and 400 in the other two zones. In Norway, the wrasse fishing season opens on 17th July south of Stadt (62°N) and 31st July north of Stadt and lasts until 20th October throughout the country.

For regulation of the husbandry and use of cleaner fish in aquaculture, the Aquaculture facility Act (FOR-2008-06-17-822), is of relevance for this report. § 28 of this Act states that “Cleaner fish that are cohabited with other fish in aquaculture facilities, shall be sorted out and humanely euthanized, or reused, prior to emptying the production pen”. It is therefore not a legal option to release the fish into the environment after use.

See also 1.4.4.2 for more information on size limit regulations of wild caught fish.

## 1.5 Important cleaner-fish species

Of the wrasses, wild-caught goldsinny wrasse and corkwing wrasse are the most important species in terms of number and value. The use of ballan wrasse is low in comparison, due to their lower natural abundance (Skiftesvik et al. 2013). However, ballan is highly prized by salmon farmers and fishers are paid more than twice as much for ballan wrasse (33 NOK per individual) as they are for the other wrasse species (13.75 NOK; https://www.vnf.no/fiskeri/leppefisk/) in 2018. The probable reason is that ballan wrasses are larger and more suitable for stocking with larger salmon; in addition, ballan wrasse is generally regarded as the most effective cleaner fish (Skiftesvik et al. 2013, 2017).

Lumpfish is more cold-adapted than the wrasses, and thus survival and growth rates in sea cages are higher than of wrasses during the winter months, but wrasses have shown better performance as cleaner fish in the summer months (Skiftesvik et al. 2017, 2018). Hence, lumpfish and wrasses are used as complementary treatments (Davie et al. 2018).

Not all wrasses that are indigenous to Norwegian waters are suitable, or used, as cleaner fish. The rock cook (*Centrolabrus exoletus*) is a naturally abundant wrasse (Skiftesvik et al. 2014b) but is less desired by fish farmers as a cleaner fish, and is regarded as unsuitable for long-distance transport due to high mortality rates in captivity (Johan Lindhom, Fjordservice pers. comm). Capture of rock cook is not permitted in Sweden. The cuckoo wrasse (*Labrus* *mixtus*) is commonly caught as bycatch in the wrasse fishery, but, to the best of our knowledge, is not used as cleaner fish; no Norwegian landings were reported during 2018. The scale-rayed wrasse (*Acantholabrus palloni*) occupies deeper waters and is rarely caught in the commercial wrasse fisheries. Hence, these three species are not considered further in this report.

### 1.5.1 Corkwing wrasse (Grønngylt) (*Symphodus melops* (Linnaeus, 1758))

Corkwing is the second-largest wrasse species in Scandinavia. They can reach up to 25 cm in Norway, but it is rare to find specimens above 22 cm (Halvorsen et al. 2016a). The corkwing is relatively short-lived compared with the other wrasse species; south and east of Jæren, individuals rarely reach more than 4 years of age, while north of Jæren, they may live for eight years (Uglem et al. 2000; Halvorsen et al. 2016a). Fish belonging to the southern group also grow faster (Halvorsen et al. 2016a). These geographic differences in life histories are mirrored by genetic structuring (Gonzales et al. 2016, Faust et al. 2018). Corkwing wrasses spawn in nests built by the males, who alone care for the larvae until they hatch (Potts 1985; Halvorsen et al. 2016a). A minority of males develop as female mimics and do not build nests but rather perform sneak spawning (Uglem et al. 2000). The male morphs are fixed for life and are possibly genetically determined. The spawning period of corkwing wrasse is from May to July, which overlaps with the spawning periods of the other wrasse species (Skiftesvik et al. 2014b; Halvorsen et al. 2016b). Catch of corkwing wrasse is currently managed by a minimum size limit of 12 cm in Norway (Table 1.4.4.2-1). As a consequence, catches may be sex selective as nesting males grow faster and mature later than females and sneaker males (Halvorsen et al. 2016a,b).

#### *1.5.1.1 Distribution*

Corkwing wrasse is distributed from Morocco to mid-Norway (Costello 1991a; Knutsen et al. 2013), as illustrated in Figure 1.5.1.1-1. In a large-scale field survey in 1996, no corkwing wrasse were caught in the Flatanger area in Northern Trøndelag (Maroni and Andersen 1996), but the species has recently colonized this area and is now occasionally caught in Nordland (Faust et al. 2018). The abundance of corkwing is highest in western Norway, but it is also relatively high in Skagerrak (Halvorsen et al. 2016a).

#### *1.5.1.2 Genetic structure*

Genetic differentiation is high between corkwing wrasse in Scandinavia and populations in the UK and further south in Europe, and the genetic diversity in Scandinavia is considerably lower (Robalo et al. 2012; Knutsen et al. 2013). The most likely explanation for the reduced genetic diversity in Scandinavia is one or several bottlenecks or founder events since the last glaciation. The discontinuity in hard-bottom coastal habitat between Scandinavia and southern populations is likely to prohibit gene flow. The corkwing wrasse nests on hard-bottom substrate and needs access to specific macroalgae for nest building (Potts 1985). The short pelagic phase of larvae is also a limiting dispersal factor (Knutsen et al. 2013).

**Figure 1.5.1.1-1:** Distribution of corkwing wrasse.

There is also a strong genetic structure within Scandinavia, particularly between Skagerrak and western Norway (Gonzalez et al. 2016, Faust et al. 2018). The most likely explanation for this is that a large sandy stretch of coastline at Jæren in Rogaland is thought to provide scant nesting habitat for corkwing wrasse. The genetic break aligns with pronounced life history differences, with corkwing in Skagerak and Kattegat growing faster, maturing earlier, and having half the life span of those north of Jæren (Uglem et al. 2000; Halvorsen et al. 2016a). Along the west coast of Norway a pattern of isolation by distance has been detected whereas very low genetic differentiation has been observed along the Skagerrak coast. The more heterogenous coastline in Western Norway could be an explanation, as the presence of deep and wide fjords could prevent gene flow (Gonzalez et al. 2016).

Using a genomic approach, Faust et al. (2018) documented that a substantial proportion of wild corkwing wrasse in the Flatanger area in Trøndelag had either Skagerrak genotypes or were hybrids (first-generation or second-generation offspring of Skagerrak corkwing). This is strong evidence of escape of Skagerrak corkwing in Central Norway, but also that these highly genetically differentiated populations have hybridized there. As only 40 individuals were analysed, further studies are needed to quantify the extent of this genetic change.

## 1.5.2 Ballan wrasse (Berggylt) (*Labrus bergylta* Ascanius, 1767)

Ballan wrasse can reach up to 60 cm in length and 29 years of age. The species is a sequential hermaphrodite; all individuals are born female and change gender after attaining between 34 and 41 cm in length (Dipper et al. 1977; Darwall et al. 1992a; Muncaster et al. 2013). The large size of ballan wrasse mean that it is particularly useful as cleaner fish in pens with larger, second-year, salmonids (Skiftesvik et al. 2013). The abundance of ballan wrasse in Norway is lower than that of the other wrasse species (Skiftesvik et al. 2014b; Halvorsen et al. 2017a). The effects of fishing on ballan wrasse have been poorly studied, but, given the species complex life history (sex change, long lifespan), it may be more vulnerable to overfishing than the other wrasse species (Darwall et al. 1992b). The minimum size limit for capture of ballan wrasse is currently 14 cm, which does not protect the mature fish.

### *1.5.2.1 Distribution*

On a large scale, the distribution of ballan wrasse is similar to the distributions of corkwing and goldsinny wrasse, extending from North Africa to Trøndelag (Costello 1991)(Figure 1.5.2.1-1) In recent scientific surveys (Figure 1.7.6-1). The species has been found sparsely up to 66.5°N, somewhat further north than corkwing (65°N) but south of the goldsinny range edge (69.5°N).

**Figure 1.6.2.1-1:** Distribution of ballan wrasse.

#### *1.5.2.2 Genetic structure*

The genetic structure of ballan wrasse has not been as thoroughly studied as that of corkwing wrasse, but much is known. A study using mitochondrial DNA found low levels of genetic structuring around the British Isles, but a high level of differentiation between the British Isles and southern Norway, and significant genetic structuring between two nearby locations (Søgne and Hidra) on the Norwegian west coast (D'Arcy et al. 2013). In addition, a general decrease in genetic variation with increasing latitude has been observed for ballan wrasse (D'Arcy et al. 2013, Quintela et al. 2016, Almada et al. 2017). In a recent population-genetics study on ballan wrasse using both single-nucleotide polymorphisms (SNPs) and microsatellites, two distinct genetic clusters were observed, representing northwestern and southeastern Scandinavia, with little genetic differentiation within these areas (Seljestad 2019). The genetic break between these two clusters was associated with the long stretch of sandy-bottom substrate on the Jæren coast in southern Rogaland, like genetic break observed for corkwing wrasse. As ballan and corkwing wrasses have similar habitat requirements, and both species provide parental care and have small home ranges, it is plausible to assume that the lack of hard substrate is a genetic barrier for both ballan wrasse and corkwing wrasse.

Ballan wrasses have two colour morphs (spotted and plain). The morphs display different life-history strategies, with plain fish investing more in reproduction and spotted fish having a faster growth rate and attaining a larger size (Villegas-Rios et al. 2013). A study using microsatellite markers revealed large genetic differences between these morphs in the Galician coast in north-western Spain, suggesting that the different morphs could comprise sympatric cryptic species (Quintela et al. 2016). These larger scale results were subsequently confirmed by the study combining microsatellites and SNPs (Seljestad 2019), though no genetic differences between the two morphs were observed in Scandinavian localities where both forms were present.

### 1.5.3 Goldsinny wrasse (Bergnebb) (*Ctenolabrus rupestris* (Linnaeus, 1758))

The goldsinny is our smallest wrasse. Although it can attain 20 years of age and 20 cm in length (Darwall et al. 1992b; Sayer et al. 1995b), it is rare to find individuals larger than 16 cm in Norwegian waters (Halvorsen et al. 2017a,b). Goldsinny males defend small territories during the spawning season and are broadcast spawners. Most eggs are pelagic, but a smaller proportion sinks to the bottom, indicating that local self-recruitment may occur (Hilldén 1984). The minimum size limit for capture of goldsinny wrasse is 11 cm. The growth rate of goldsinny may be highly variable over small spatial scales; populations with different growth rates may be differently affected by fishing (Olsen et al. 2018).

### *1.5.3.1 Distribution*

On a large scale, the distribution of goldsinny wrasse is similar to the distributions of corkwing and ballan, extending from North Africa to Trøndelag (Costello 1991) (Figure 1.5.3.1-1). In recent scientific surveys (Figure 1.7.6-1), it has been found sparsely up to (69.5° N), somewhat further North than corkwing (65°N) and ballan wrasse (66.5° N).

**Figure 1.5.3.1-1:** Distribution of goldsinny.

### *1.5.3.2 Genetic structure*

A study using microsatellites to investigate the genetic population structure of goldsinny revealed a clear isolation-by-distance pattern (Jansson et al. 2017). Unlike corkwing and ballan wrasses, goldsinny wrasse has a pelagic egg stage that may facilitate gene flow over long distances (Darwall et al. 1992, Potts 1985, Hillden 1984). Genetic exchange between goldsinny of southern Scandinavian origin and local populations in Trøndelag has been suggested, because these two populations more closely related than would be expected from the geographic distance that separates them (Jansson et al. 2017).

## 1.5.4 Lumpfish (Rognkjeks) (*Cyclopterus lumpus* (Linnaeus, 1758))

Lumpfish live in temperate and cold waters and are distributed across the boreal region of the Atlantic Ocean. The species occupies differing habitats depending on life stage, and lumpfish may undertake extensive annual migrations between their feeding grounds found in deeper (offshore) waters in winter and shallow coastal spawning areas in spring and summer (e.g. Blacker, 1983). The species displays homing behaviour and may return to the same breeding area for consecutive years (Kennedy et al. 2015), which could favour reproductive isolation and, consequently, population differentiation. Prior to spawning, males establish territories on rocky substrate and eggs undergo paternal care throughout the incubation period. Using a specialized suction cup, larvae attach to the substrate soon after hatching, which probably limits larval dispersal (Davenport, 1985). Spawning time may vary by several months within a single population (Wittwer and Treasurer, 2018), and up to seven months among populations, from January in the English Channel (Powell et al. 2018) to August in the northern part of the distribution range (Jónsdóttir et al. 2018). Lumpfish is a benthopelagic species that can be found at depths below 800 m, most commonly at 50 to 150 m (Parin et al. 2002). Lumpfish may live for up to 14 years and normally mature at 3–5 years of age, although some populations mature after only 2 years (reviewed in Powell et al. 2018). Notably, lumpfish from the Baltic Sea are generally smaller in size, grow at a slower rate, and mature at a much smaller size (150 g) than lumpfish from the North Atlantic (2.0–3.0 kg) (Whittaker et al. 2018). The slow growth rate in Baltic lumpfish could make them attractive for the aquaculture industry as they might feed on sea lice for a longer period (as feeding on sea lice decreases with increasing cleaner size). However, given their markedly different genetic structure, care should be taken to ensure that Baltic lumpfish do not escape and interbreed with Atlantic lumpfish populations (see section 1.5.4.2). Lumpfish has been classified as “Near threatened” in the IUCN Red List (Lorance et al. 2015), but limited information is available on the conservation status of different populations.

#### *1.5.4.1 Distribution*

In the northwest Atlantic, lumpfish are found in the western Atlantic from Cape Cod to Greenland. In the northeast, Atlantic lumpfish are distributed from south of Portugal, through the British Isles, the North Sea and into Kattegat and the Baltic Sea. Furthermore, this species is distributed along the Norwegian coast and into the Barents Sea, where the distribution stretches all the way up to Spitsbergen in the northwest and to Novaya Zemlya in the northeast. Additionally, lumpfish are present in Faroe and Icelandic waters, and their distribution stretches across the Atlantic Ocean to the coast of Greenland (Figure 1.5.4.1-1).

#### *1.5.4.2 Genetic structure*

Little is currently known about the genetic structure of lumpfish. Significant genetic differences have been found at large spatial scales using microsatellite markers (Pampoulie et al. 2014, Whittaker et al. 2018), but little distinct genetic differentiation has been detected at a smaller spatial scale, except for a pattern of isolation-by-distance in Greenland waters (Garcia-Mayoral et al. 2016). Pampoulie et al. (2014) found three genetically distinct regions: a north-western group (Maine/Canada/Greenland), a north-eastern group (Iceland/Norway), and the Baltic Sea. Whittaker et al. (2018) observed a significant degree of population structure that indicates a finer genetic structuring, with genetically distinct groups found in the West Atlantic (USA/Canada), Mid-Atlantic (Iceland), East Atlantic (Faroe

Islands/Ireland/Scotland/Norway/Denmark), English Channel, Averøy (Norway), and the Baltic Sea (Sweden).

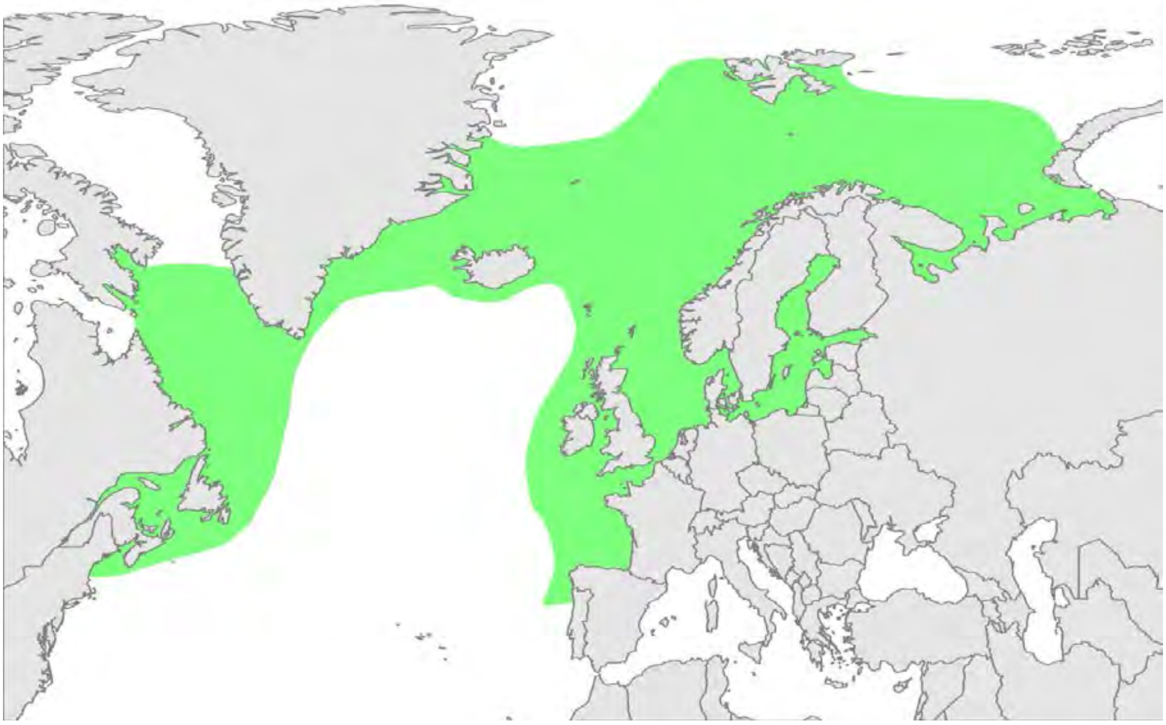

**Figure 1.5.4.1-1:** Distribution of lumpfish.

Although Whittaker et al. (2018) detected significant gene flow within each of these groups (consistent with moderate isolation-by-distance), little exchange of migrants was found among these areas. At a smaller spatial scale, significant structuring with isolation-by-distance has been observed between west Greenland samples and two genetically distinct groups identified between north- and south Greenland (Garcia-Mayoral et al. 2016). Such results indicate the presence and the potential of fine-scale genetic structuring in this species. However, little fine-scale genetic structure was found in the English Channel (Consuegra et al. 2015) or along the Norwegian coast (Jónsdóttir et al. 2017).

## 1.6 Problems related to translocation or import of cleaner fish

Numerous organisms infect cleaner fish in their natural habitats and native ranges. However, these infectious organisms are not evenly distributed over the ranges of the different cleaner-fish species. In general, both the number of infectious species and the abundance of each infectious species are highest in the core area of a species and are lowest in the most peripheral areas of its range. Thus, translocation of cleaner fish from one area to another, especially to more peripheral areas, may result in the spread of infectious organisms. Furthermore, even if an infectious species in the translocated fish is already present in the recipient area, intra-species differences (e.g. in virulence) may exist, and the introduced strain may thus change the previously balanced relationship between the infectious species and its fish-host population.

The introduction of one new species or a new genotype of an infectious organism may not necessarily have an observable effect in the fish-host population. However, if several species or genotypes of infectious organisms are introduced, they may, in sum, have negative consequences, such as reduced fecundity, decreased growth, and increased mortality, for the host population (Lymbery et al. 2014) Prokaryotic and unicellular eukaryotic infectious organisms in fish usually have only one host in their lifecycle. Thus, introduction of such organisms will mainly affect the fish host. However, many multicellular parasites (such as myxozoans, trematodes, cestodes, and nematodes) use different invertebrates as intermediate hosts in their lifecycles (Marcogliese, 2005). Thus, the introduction of such parasites with translocation of cleaner fish may also have a negative effect on local populations of marine invertebrates.

### 1.6.1 Introduction of novel parasites

More than a hundred different species of parasites have been documented for the five wrasse species used as cleaner fish in Norway (Egil Karlsbakk pers. comm., in VKM (2017)). However, the occurrence and geographical distribution of these parasites are mostly unknown, as is the genotypic diversity within each parasite species.

Parasites of wrasse species and lumpfish have been mainly studied in Ireland, Norway, and Scotland (e.g. Costello et al. 1996; Karlsbakk et al. 1996, 2014; Treasurer, 1997). We have been unable to find any documentation describing the occurrence of parasites in the relevant cleaner-fish species in the coastal areas of Sweden or Denmark. One possible assumption is that the parasite communities in wrasse species on the Danish and Swedish coasts of Skagerrak, and possibly Kattegat also, resemble those on the Norwegian southeastern coast of the Skagerrak basin. This assumption is based on the genetic similarity of the wrasse species in the Skagerrak basin and on the basin's oceanography (Faust et al. 2018, Jannson et al. 2017, Seljestad 2019). However, the parasite fauna in wrasse on the west coast of Denmark may be more similar to the wrasse parasites on the coasts of Ireland and UK (Costello et al. 1996; Treasurer, 1997, 2012).

In Norway, the number and abundance of parasite species that are specific to wrasse are likely to be the lowest in the peripheral distribution areas of each wrasse species at the Norwegian northwest coast. Off the west coast of Norway, near Bergen, Steigen et al. (2018) examined five wrasse species for the presence of gill parasites (Table 1.6.1-1). Harkestad et al. (2010) observed *Ichthyosporidium gigantum* (Microsporidia) in corkwing wrasse from the same area.

Table 1.6.1-1. Parasites in five wrasse species in coastal areas in western Norway (after Steigen et al. 2018)

| Wrasse species | Ballan | Cuckoo | Rock cook | Goldsinny | Corkwing |
|---|---|---|---|---|---|
| Scientific name | *L. bergylta* | *L. mixtus* | *C. exoletus* | *C. rupestris* | *S. melops* |
| *Ichthyobodo* spp. | x | x | x | x | x |
| Trichodinids | | x | | x | x |
| *Paramoeba perurans* | x | x | | | |
| *Hatschekia* sp. | x | | | | |
| *Caligus centrodonti* | x | | | | |
| *Paranucleospora theridion* | x | x | x | x | x |

Karlsbakk et al. (1996) found 17 parasite species in goldsinny wrasse from the southeastern coast of Norway (Table 1.6.1-2) and concluded that the parasite community is depauperate, both in species number and abundance. Compared with Mediterranean wrasse species, the metazoan community is less diverse, particularly because of a lower abundance of ectoparasitic crustaceans, and the intestinal helminth community is also depauperate (Karlsbakk et al. 1996).

Table 1.6.1-2. Parasites of goldsinny wrasse from coastal areas in southeast Norway (after Karlsbakk et al. 1997)

| Wrasse species | Goldsinny |
|---|---|
| Scientific name | *C. rupestris* |
| *Cryptobia* sp. | x |
| *Trichodina* sp.1 | x |
| *Trichodina* sp.2 | x |
| *Paratrichodina* sp. | x |
| *Cryptocotyle lingua* | x |
| *Lecithochirium* sp. | x |
| *Derogenes varicus* | x |
| *Lecithaster gibbosus* | x |
| *Grillotia erinaceus* | x |
| *Cosmocephalus obvelatus* | x |
| *Paracuaria adunca* | x |
| *Hysterothylacium aduncum* | x |
| *Contracaecum septentrionalis* | x |
| *Echinorhynchus gadi* | x |
| *Corynosoma semerme* | x |
| *Hatschekia cluthae* | x |
| *Caligus centrodonti* | x |

Costello et al. (1996) and Treasurer (1997) found 42 and 35 species of parasites, respectively, in the wrasse species that they examined, and found that most parasites were specific to the wrasse species occurring along the coast of Ireland and Scotland, including several ectoparasitic crustaceans and intestinal helminths (Table 1.6.1-3). Thus, it can be assumed that translocation of wrasses from coastal areas of Sweden and Denmark to areas on the coast of Trøndelag and Nordland could result in the spread of new species or genotypes of parasites specific to a wrasse species, especially those with direct, single-host lifecycles. The likelihood of introduction of novel parasites or genotypes probably increases the further south the fish are caught.

Table 1.6.1-3. Parasites in five wrasse species in coastal areas of Ireland and Scotland (after Costello et al. 1996 and Treasurer, 1997)

| **Wrasse species** | **Ballan** | **Cuckoo** | **Rock cook** | **Goldsinny** | **Corkwing** |
|---|---|---|---|---|---|
| **Scientific name** | *L. bergylta* | *L. mixtus* | *C. exoletus* | *C. rupestris* | *S. melops* |
| *Ichthyobodo* **spp.** | x | x | x | x | x |
| **Bodonidae (*Cryptobia* sp.)** | | | x | x | x |
| *Trichodina rectuncinata* | x | | x | x | x |
| *T. labrorum* | | | | | x |
| *T. ovonucleata* | x | | x | x | x |
| *Trichodina* **spp.** | | x | x | x | x |
| **Microsporidia** | | | | x | x |
| *Eimeria* **sp.** | | | | x | x |
| *Goussia* **sp.** | | | | x | x |
| *Spaerospora divergens* | | | | | x |
| *Davisia* **sp.** | | | | x | |
| *Ortholinea divergens* | | | x | | |
| *Microcotyle donavini* | x | | x | x | |
| *Gyrodactylus* **sp.** | | | x | | |
| *Hatschekia cluthae* | x | | x | x | x |
| *H. labracis* | | x | | | x |
| *Hatschekia* **sp.** | | | x | x | x |
| *Leposphilus labrei* | | | x | | x |
| *Caligus centrodonti* | x | | x | x | |
| *C. elongatus* | x | | x | x | |
| *Cryptocotyle lingua* | x | x | x | x | x |
| *Macvicaria alacris* | x | x | x | x | x |
| *Gaevskayatrema perezi* | | | x | x | x |
| *Galactostomum lacteum* | | | | x | x |
| *Galactostomum* **sp.** | | | | x | x |
| *Helicometra fasciata* | | x | | | x |
| *Podocotyle* **sp.** | | | | x | x |
| *Proctoeces* **sp.** | | | x | x | x |
| *Prosorhynchus aculeatum* | | | | | x |
| **Immature Allocreadidae** | | | | x | x |
| *Peracreadium commune* | x | | | | |
| *Peracreadium genu* | x | | | | |
| *Helicometra pulchella* | | x | | | |
| *Lecithochirium rufoviride* | | | x | x | x |
| *Echinorhynchus* **sp.** | | | x | x | |
| *Echinorhynchus gadi* | | | | | x |
| *Polymorphus* **sp.** | | | | | x |
| **Cystacanth (unidentified)** | | | | x | x |
| *Contracaecum osculatum* | x | | | x | |
| *Contracaecum* **sp.** | | | x | x | x |
| *Hysterothylacium aduncum* | x | | | x | x |
| *Hysterothylacium* **sp.** | | | x | x | x |
| *Raphidascaris* **sp.** | | | x | x | x |
| *Anisakis simplex* | x | | | x | |
| **Anisakid nematode** | x | | | x | |

In contrast with the wrasses, the coastal areas of Norway are part of the core distribution area of lumpfish (see Figure 1.5.4.1-1). At least 59 parasite species have been found in Norwegian lumpfish (Karlsbakk et al. 2014), including most, if not all, of the parasite species found in lumpfish in other regions (e.g. Rolbiecki and Rokicki, 2008; Cavin et al. 2012). In addition, the protist *Ichthyophonus hoferi* (Mesomycetozoea) occurs in farmed lumpfish (Mo and Poppe 2018). The protist is yet to be detected in wild cleaner fish, but as this mesomycetozoean (Ichthyosporean) is widely spread among marine fish species, its presence in wild cleaner fish can be expected. Thus, novel parasites are probably less likely to be introduced with imported lumpfish than with wrasses. Nevertheless, novel genotypes may be introduced, with unforeseen consequences.

### 1.6.2 Introductions of exotic infectious bacterial agents

Bacterial pathogens are amongst the main contributors to cleaner fish mortalities in Norwegian aquaculture, irrespective of fish species (Nilsen et al. 2014; Hjeltnes et al. 2018). Some agents, such as 'atypical' *Aeromonas salmonicida*, *Vibrio anguillarum*, and an unnamed *Pasteurella* sp., may cause mortality episodes in apparently uninfected specimens of one or more cleaner-fish species (Alarcón et al. 2016; Biering et al. 2016). Other bacteria, such as various environmental *Vibrio* species, presumably play a role as secondary pathogens in otherwise-weakened specimens (Gulla et al. 2015, 2017). Other bacterial diseases of cleaner fish in Norway include *Vibrio ordalii*, *Pseudomonas anguilliseptica*, *Tenacibaculum* spp., *Moritella viscosa*, and *Aliivibrio* spp. (e.g. Hjeltnes et al. 2018).

Many of the bacteria commonly recovered from cleaner fish mortalities in Norway have also been described from cleaner-fish species elsewhere in Europe, e.g. the British Isles (e.g. Treasurer, 2012; Marcos-López et al. 2013). Seen as a whole, import of infected cleaner fish presumably does not contribute dramatically towards an increase in risk to biodiversity in Norway, as, to the best of our knowledge, all bacterial species that have so far been reported in association with disease in non-Norwegian cleaner fish, have also, at some point, been reported from Norwegian cleaner fish. It is worth noting, however, the detection of *Piscirickettsia salmonis* from diseased lumpfish in Ireland (Marcos-López et al. 2017); this has been sporadically found in farmed Atlantic salmon in Norway, but not in cleaner fish (Olsen et al. 1997).

Although the bacterial pathogens of cleaner fish in Norway and abroad currently appear similar at the species level, strain differences at the sub-species level between geographic areas may be of considerable importance. As has become increasingly obvious over recent years, the population structures of bacterial pathogens are commonly characterized by an array of genetic subtypes, often distinguishable by, for example, differences in host specificity and virulence. For instance, *Aeromonas salmonicida*, a species capable of causing disease in an extremely wide range of piscine hosts (Austin and Austin, 2012), can be further separated into a range of apparently host-specific genetic subtypes (*A*-layer types) (Gulla et al. 2016). Two such subtypes appear particularly virulent towards cleaner-fish species, having been recovered from almost all *A. salmonicida*-related mortalities recorded in Norwegian cleaner fish.

With the exception of the British Isles, the availability of scientific literature regarding bacterial infections in cleaner-fish species outside of Norway is relatively scarce. It is therefore presently unknown whether particularly virulent bacterial agents with an affinity for cleaner-fish species exist in other countries but are exotic to Norway. Importantly, this applies not only to bacteria at the species level, but also at sub-species levels, where significant variations that have yet to be discovered may occur.

Brief descriptions of some bacterial species associated with disease in marine fish, although some yet undetected in cleaner-fish species, follow below.

#### *1.6.2.1 Aeromonas salmonicida*

Although the species is present in Norway, multiple (>20) distinct subtypes (genotypes) have been documented from different fish species around the world, several of which have not yet been found in Norway (Gulla et al. 2019). A significant degree of host specificity seems to occur within individual subtypes of the bacterium, and two such have been found as almost exclusively dominating amongst *A. salmonicida* cases in cleaner fish (Norway and on the British Isles). Today, most farmed cleaner fish in Norway are vaccinated against these two strains. It remains unknown whether *A. salmonicida* subtypes that are exotic to Norway, but able to infect one or more of the cleaner-fish species used in Norway, exist in any of the relevant cleaner fish export areas. Furthermore, *A. salmonicida* subsp. *salmonicida* constitutes one subtype that can cause the disease furunculosis (included on the Norwegian Food Safety Authority List-3 of notifiable diseases of aquatic organisms) primarily in salmonid fish. While all farmed Atlantic salmon in Norway have been vaccinated against furunculosis since the early 1990s, it still occurs sporadically amongst wild salmonids in some areas along the Norwegian coast. Although presumably not the main target host for this subtype, both wrasses and lumpfish are susceptible to infection by it (e.g. Hjeltnes et al. 2018; Treasurer, 2012).

#### *1.6.2.2 Vibrio anguillarum*

*Vibrio anguillarum*, primarily serotypes O1 and O2, causes classical vibriosis in several fish species, and is occasionally recovered from dead cleaner fish in Norway (Bornø and Gulla, 2016). Challenge experiments have verified it as being pathogenic towards both ballan wrasse and lumpfish (Biering et al. 2016; Rønneseth et al. 2014). Atlantic salmon are susceptible to the disease, but all farmed salmon in Norway today are vaccinated. *V. anguillarum* is ubiquitous in marine environments (Sørensen and Larsen, 1986).

#### *1.6.2.3 Vibrio ordalii*

*Vibrio ordalii*, a very close relative of *V. anguillarum*, is sporadically associated with disease in lumpfish used as cleaner fish in Norway (Bornø and Gulla, 2016). *V. ordalii* has caused disease outbreaks in farmed salmon, e.g. in Chile (Colquhoun et al. 2004), but phylogenetic investigations have revealed genetic differences between Pacific- and North-Atlantic strains (Steinum et al. 2016).

#### *1.6.2.4 Vibrio* spp.

Cleaner fish are also susceptible to infections with various other members of the genus *Vibrio*, in particular *Vibrio splendidus* and *Vibrio tapetis* (Jensen et al. 2003; Bergh and Samuelsen, 2007; Harkestad, 2011; Colquhoun et al. 2012; Nilsen et al. 2014). Infection trials have, however, provided conflicting results, and recent studies indicate that these bacteria may represent opportunistic pathogens (Gulla et al. 2015; 2017). These trials were undertaken on relatively small fish that seem to decompose particularly rapidly, which may complicate diagnostic work due to colonization by saprophytic bacteria. This includes *V. splendidus*-related strains, which represent a highly diverse group of bacteria that dominates in marine bacterioplanktons (Thompson et al. 2005).

#### *1.6.2.5 Tenacibaculum* spp.

*Tenacibaculum* spp. infections are associated with non-systemic ulcerative conditions in many fish species, including salmon. Members of the genus *Tenacibaculum* are often recovered from eroded fins and ulcers in cleaner fish (Bornø and Gulla, 2016; Nilsen et al. 2014). A recent study examining isolates from various farmed marine-fish species in Norway found only a very limited degree of association between host-fish species and *Tenacibaculum* genotype (Olsen et al. 2017). The natural abundance of *Tenacibaculum* spp. in marine environments must, however, be considered, and prior damage to the skin barrier is likely to be strongly predisposing for such infections. *T. maritimum*, the *Tenacibaculum* species most commonly associated with disease in marine fish globally, has been sporadically detected in cultured juvenile lumpfish with skin lesions in Norway (Småge et al. 2016).

#### *1.6.2.6 Pasteurella skyensis / Pasteurella* sp.

Pasteurellosis, caused by a yet unspeciated *Pasteurella* sp., has caused high lumpfish mortalities since it was detected in 2012 (Alarcon et al. 2016). The aetiological agent should not be confused with *Photobacterium damselae* subsp. *piscicida* which, despite not belonging to the *Pasteurella* genus, also causes a disease termed 'pasteurellosis' in farmed marine fish in other parts of the world. The *Pasteurella* sp. usually involved in lumpfish disease in Norway is genetically closely related to, yet distinct from, *P. skyensis*, which has caused disease outbreaks in farmed salmon in Scotland (Birkbeck et al. 2002). Furthermore, it is even more closely related to the unnamed bacterial species that has sporadically caused the disease 'Varracalbmi' in farmed Norwegian salmon (Valheim et al. 2000). In 2018, however, the genotype usually found in Norwegian salmon was confirmed also from lumpfish stocked with infected salmon (Colquhoun, Fiskehelserapporten 2018). *Pasteurella* sp. (further unspecified) has also been regularly reported in lumpfish in the UK in recent years (Scholz, personal communication), but has never been reported from wrasse species elsewhere.

#### *1.6.2.7 Piscirickettsia salmonis*

In 2017, *Piscirickettsia salmonis* was reported for the first time in sick farmed lumpfish in Ireland (Marcos-Lopez et al. 2017), but has never been reported from Norwegian cleaner-fish species. *P. salmonis* is a significant problem to salmon farming in Chile, where it causes the severe disease Salmon Rickettsial Syndrome (SRS). *P. salmonis* has been sporadically recovered from farmed salmon in Europe, including Norway, but European strains appear less virulent than those in Chile (Olsen et al. 1997; Reid et al. 2004; Rozas-Serri et al. 2017). Genetic investigations indicate that the strain isolated from Irish lumpfish is closely related to isolates previously found in Atlantic salmon in Ireland (Marcos-Lopez et al. 2017).

#### *1.6.2.8 Pseudomonas anguilliseptica*

*Pseudomonas anguilliseptica* is considered an opportunistic pathogen that may cause disease in a range of freshwater and marine fish species. In Norway, infections have been documented regularly in diseased lumpfish, and it has also occurred in wrasse (Fiskehelserapporten 2018; Poppe et al. 2012).

#### *1.6.2.9 Photobacterium damselae* **subsp***. piscicida*

*Photobacterium damselae* subsp. *piscicida* causes disease in various maricultured fish species and remains problematic in the Mediterranean. Severe cases are usually observed above ~20°C, whereas prolonged subclinical infection is common at lower temperatures. It has yet to be reported in Norway and in the cleaner-fish species.

#### *1.6.2.10 Lactococcus garviae* **(and some other streptococci)**

These bacteria affect various maricultured fish species, primarily at warmer water temperatures, and may also have the potential to infect humans. *L. garviae* has been detected in wild Red Sea wrasse (Colorni et al. 2003). No detections have been reported from Norway, nor from any cleaner-fish species.

#### *1.6.2.11 Mycobacterium* **spp.**

Most fish species are susceptible to mycobacterial infection, and a prolonged, asymptomatic carrier-status is common. No reports from cleaner-fish species exist as far as we know. Some *Mycobacterium* species are present in Norwegian waters (e.g. *M. salmoniphilum* and *M. marinum*), but some are presumably not (e.g. *M. shotsii* and *M. pseudoshotsii* from the northwest Atlantic). There may be some zoonotic potential associated with these bacteria.

### 1.6.3 Introduction of exotic infectious viral agents and strains to wild wrasses

The basic scientific issues regarding viral agents, host-virus interplay, and ecological hazards of viral infections of cleaner-fish species in salmon aquaculture need to be addressed in order to identify potential threats. Brief descriptions of various relevant viruses associated with disease in marine fish are given below.

#### *1.6.3.1 Nodavirus – Nervous necrosis virus (NNV)*

Nodaviruses are, in general, not host-species specific, but infections are not commonly observed in salmonids. Brain samples from wrasses from the Swedish west coast and the Norwegian coast north to Tysfjord were recently screened for NNV by RT-qPCR (Korsnes et al. 2017). Positive samples were analyzed by sequencing and phylogenetic analysis of parts of the RNA2 gene segment. The study showed that NNV is present in wild ballan, corkwing, and goldsinny wrasses along the coast of Sweden and Norway. The overall prevalences ranged between 6.3 and 18%. The wrasse RNA2 NNV sequences revealed high genetic variation, forming three phylogenetic clusters (Korsnes et al. 2017).

#### *1.6.3.2 Viral haemorrhagic septicaemia virus (VHSV)*

VHSV infects a wide range of marine fish species, and has been isolated from more than 80 wild and farmed fish species (OIE, 2017). VHSV is divided into genogroups I-IV (Einer-Jensen et al. 2004). Differences in virulence can be ascribed to a few amino acids and low-virulence strains can mutate into highly virulent strains (Ito et al. 2016; Baillon et al. 2017). Consequently, all variants of VHSV are notifiable to OIE.

***Norway***

VHSV is present in marine fish populations in Norwegian coastal waters. In a relatively large survey, including many different species of fish, VHSV genotype Ib was detected in Atlantic herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and silvery pout (*Gadiculus argenteus*) (Sandlund et al. 2014). Testing of wild-caught cleaner fish in Norway has not detected VHSV (Bornø and Gulla, 2016).

***Scotland***

A population of wild-caught wrasses, consisting of ballan, corkwing, cuckoo, goldsinny, and rock cook, and kept in a land-based holding facility in the Shetland Isles, Scotland, experienced an outbreak of mortality due to infection with VHSV genotype III (Munro et al. 2015). The outbreak was followed up by experimentally determining the susceptibility of goldsinny wrasse to VHSV genotype III by immersion or intraperitoneal (i.p.) challenge. Cumulative moribund fish were 17% and “more than” 50% 14 days after immersion and i.p. challenges, respectively. The most pronounced histopathological changes were found in the heart, and thus differ from those described for VHS in salmonids. Virus clearance and heart tissue recovery were noted (Matejusova et al. 2016). The same authors also performed a cohabitation experiment that showed that goldsinny wrasse may shed viable VHSV, and thus can transmit the infection (Matejusova et al. 2016).

#### *1.6.3.3 Infectious pancreatic necrosis virus (IPNV)*

IPNV is, in general, not particularly host-species specific. Bath challenge experiments have shown goldsinny wrasse to be susceptible to IPNV isolated from Atlantic salmon (Gibson et al. 1998). At 2-weeks post challenge (wpc), the infection rate culminated with 30% of fish infected, and at 4 wpc the virus was no longer detectable. There were no clinical signs, histopathological changes, or mortality (Gibson et al. 1998). Testing of wild-caught cleaner fish in Norway has not detected IPNV (Bornø and Gulla, 2016).

#### *1.6.3.4 Infectious salmon anaemia virus (ISAV)*

Goldsinny wrasse has been experimentally challenged with ISAV; there were no mortalities in wrasse injected with ISAV nor in wrasse cohabiting with ISAV-infected salmon (Kvenseth, 1998; Treasurer, 2012). ISAV has been detected by RT-qPCR when wrasses have shared sea-cages with salmon during an outbreak of ISA (Bornø and Gulla, 2017). No clinical disease was observed in cleaner fish in either the PD or ISA outbreaks in salmon, and cross-contamination during sampling could not be excluded.

#### *1.6.3.5 Piscine orthoreovirus (PRV)*

PRV is ubiquitous in the marine phase of Atlantic salmon farming. At least three different genogroups of PRV have been found in salmonids, i.e., in Atlantic salmon, Coho salmon, and rainbow trout. The genogroup PRV-1 causes heart and skeletal muscle inflammation in Atlantic salmon (Wessel et al. 2017), and most detection procedures, i.e., RT-qPCR, detect this virus variant. PRV has been found in a few samples of marine fish by PCR (Wiik-Nielsen et al. 2012), and in gill and kidney samples from wrasses kept in net pens holding infected salmon, according to a student report (Persson and Røsæg, 2013). However, both findings had high Ct-values, at around the cut-off of the detection method used.

#### *1.6.3.6 Piscine myocarditis virus (PMCV)*

Ballan and corkwing wrasse have been found to be susceptible to PMCV. Scholz and colleagues (2017) reported that when ballan and corkwing wrasse cohabited with a farmed salmon population experiencing cardiomyopathy syndrome (CMS), PMCV were detected in the wrasses at a low viral load. Non-specific heart lesions were present in PCR-positive wrasse and absent in PCR-negative wrasse. However, elevated mortality in wrasse was not observed and, based on the findings described, no wrasse mortality was attributed to CMS (Scholz et al. 2017).

### *1.6.3.7 Lymphocystis disease virus*

Lymphocystis virus has been detected in wrasse living in warm waters (Bluestreak cleaner wrasse, *Labroides dimidatus*). The virus has been found in more than 140 fish species (Essbauer and Ahne, 2001). Lymphocystis virus belongs to the family Iridoviridae.

### *1.6.3.8 Salmonid alphavirus (SAV)*

Salmonid pancreas disease virus is more commonly known as salmonid alphavirus (SAV). Diseases due to SAV have only been described in salmonid fish, suggesting that it is host specific. However, SAV-positive marine flatfish species have been reported in the vicinity of SAV-infected salmon farms (McCleary et al. 2014; Snow et al. 2010). The virus is spread horizontally by shedding through natural excretions/secretions, such as faeces and mucus (Graham et al. 2012). SAV is currently split into six subtypes based on the sequences of the genes nsp3 and E2. Transmission via waterbodies containing the virus depends on hydrographic conditions and may show considerable variation, depending on time and geography.

SAV has been isolated from a pooled sample of ballan wrasse in Ireland, showing no signs of disease (Ruane et al. 2018). Partial sequencing of the E2 and nsP3 genes showed that it was closely related to SAV subtype 6.

SAV has been detected by RT-qPCR in wrasses that shared sea-cages with salmon during an outbreak of pancreas disease (PD) (Hjeltnes et al. 2017). No mortalities or signs of PD were observed, when wrasses were experimentally infected with SAV, supposedly SAV1 or SAV2 (Gibson and Sommerville, 1996).  When ballan wrasses were i.p. injected with the salmon-adapted SAV2 and SAV3 they did not become infected (Røsaeg et al. 2017), indicating a lack of susceptibility. This contrasts with the findings of infections with SAV6 in ballan wrasse, or it could be that the SAV6 subtype is adapted to ballan wrasse. There does not appear to be any epidemiological link between SAV6 found in ballan wrasse in Ireland and SAV of farmed Atlantic salmon in Ireland, the latter being subtype SAV1. In a large-scale meta-transcriptomic approach, s previously undescribed alphaviruses, in fish, amphibians and reptiles were described (Shi et al. 2018). Thus, the diversity of alphaviruses in the marine environment is greater than previously thought.

## 1.6.4 Introduction of exotic infectious viral agents and strains to wild lumpfish

### *1.6.4.1 Viral haemorrhagic septicaemia virus (VHSV)*

VHSV genotype IV was detected in lumpfish in Iceland in 2015 (Guðmundsdóttir et al. 2018). The VHSV infected fish had been caught for use as broodfish in a lumpfish farm and the virus was following isolated from progeny with severe mortality. Experimental infection by injection, immersion and cohabitation revealed low survival in cohabitants and injected fish. Despite intensive screening VHSV have not been isolated in Iceland since 2015. Screening has, so far, not revealed VHSV in lumpfish in Norway. See 1.6.3.2 for more details on the pathogen in general.

#### *1.6.4.2 Flavivirus infection in lumpfish,* **Cyclopterus lumpus** *virus (CLuV)*

In 2015, a new disease emerged in Norwegian culture facilities for lumpfish, characterized by liver necrosis and resulting in more than 50% mortality among young fish. This led to the detection of a previously undescribed virus, belonging to the *Flavoviridae* family. The virus has been tentatively designated *Cyclopterus lumpus* virus (CLuV) (Skoge et al. 2018). Verification is needed that CLuV was indeed the causative agent of the reported disease in lumpfish, and not a coincidental finding. Using RT-PCR screening of wild and farmed lumpfish, CLuV was detected only in lumpfish suffering from the disease described above and was not found in healthy lumpfish (Skoge et al. 2018).

#### *1.6.4.3 Lumpfish ranavirus*

Ranavirus is a genus in the family Iridoviridae. A ranavirus has been isolated from lumpfish at multiple locations in the North Atlantic area. Initially isolated in the Faroe Islands in 2014, the virus was subsequently found in lumpfish from Iceland in 2015, and in Scotland and Ireland in 2016 (Stagg et al. 2017). The virus causes a cytopathic effect in many cell lines. Partial sequences of eight isolates showed high similarity, and comparison with other ranaviruses showed high homology with ranaviruses from cod (*Gadus morhua*) and turbot (*Psetta maxima* syn*. Scophthalmus maximus*) isolated in Denmark in 1979 and 1999. Phylogenetic analysis suggests that this ranavirus is related to epizootic haematopoietic necrosis virus (EHNV) (Stagg et al. 2017). EHNV is an iridovirus that is widespread in Australia, and is known to affect farmed rainbow trout, causing epizootic haematopoietic necrosis that is notifiable to OIE.

#### *1.6.4.4 Nervous necrosis virus (NNV)*

NNV is, in general, not host species-specific. They are commonly found in marine fish species, but infections are not commonly observed in salmonids. NNV has, however, not been reported in lumpfish juveniles.

### 1.6.5 Introduction of exotic infectious fungal pathogens

The occurrence of fungi in wild wrasse species and lumpfish is mostly unknown. Powell et al. (2018) reported that fungal infection is common in adult lumpfish in captivity and can be a major cause of disease. Several species of fungi are probably involved, but those belonging to the genus *Exophiala* appear to be most common (Powell et al. 2018). Mo and Poppe (2018) reported the occurrence of *Ichthyophonus hoferi* in farmed lumpfish.

### 1.6.6 Problems related to genetic changes of local populations

Populations are locally adapted when, in the specific habitat, the characteristics of fitness (survival and reproduction rates) of individuals with local genotypes are higher than those of introduced individuals with different genotypes (Kawecki and Ebert 2004, Sotka 2005). For a locally adapted population, environmental alterations may reduce fitness and can be counteracted either by range shifts, by a phenotypic response (phenotypic plasticity), or over generations by evolutionary change (adaptation). Adaptation requires genetic variability in phenotypic traits (e.g. physiology, behaviour, life history, morphology). The level of genetic variability (i.e., adaptability) may vary among populations. Gene flow from introduced populations will, in many cases, counteract the effects of local adaptation through the introduction of genotypes that have been selected for in a different environment (e.g. Bridle and Vines 2007) and may cause genetic incompatibilities between the source and recipient populations. Hence, to transfer individuals (intentionally or unintentionally) between spatially distant and genetically distinct populations is likely to result in genetic changes to the native populations. Such changes could involve shifts in allele composition, loss of genetic variation, eradication of local adaptation, and a decline in population structuring (Laikre et al. 2010). Hence, translocating individuals from one native population to another should, ideally, only occur when the populations are genetically identical. If populations are genetically distinct, outbreeding depression (i.e., fitness loss due to break down of locally adapted genotypes) could result from crossbreeding (e.g. Lynch 1991, Waples 1991, Waser 1993).

In general, it is difficult to trace the processes causing changes in genetic diversity as it is usually identified long after the occurrence of the translocation or may go unnoticed. Hence, fine-scale molecular markers are needed and should be used to identify population structure before a translocation has taken place, otherwise unique genetic populations may be lost (e.g. Hammer et al. 2007). Since selection may be a much more rapid process than random genetic drift, genetic markers under selection may better reflect more recent population divergence (Reiss et al. 2009).

The Atlantic cod (*Gadus morhua*) in the Baltic Sea is an example of local adaptation and the potential consequences from loss of locally adapted genotypes. The selection pressure to adapt to the low salinity waters in the Baltic Sea is a major force influencing the spawning success of Baltic cod, and it has been shown that successful fertilization of the cod's pelagic eggs depends on a balanced buoyancy (Westin and Nissling 1991; Nissling et al. 1994). As a result, the Atlantic cod in the Baltic Sea are genetically differentiated from neighbouring populations in the Kattegat and Öresund. This has been explained as being due to local adaptation to environmental differences in salinity, sea temperature, and oxygen level (Berg et al. 2015). If such genetically adapted populations are threatened or become extinct, the potential to reintroduce the population from a new stock is minute and would result in genetic swamping, eliminating the unique environmental adaptations present. Hence, a crucial point is whether (and to what extent) source and recipient populations are, in fact, genetically distinct entities.

Within Norway, the genetic structure of wrasses has been relatively well characterized. A study of corkwing wrasse revealed highly differentiated populations, with a strong genetic break between southern and western Norway, with generally lower genetic diversity in the southern area (Blanco et al. 2016). Similarly, two genetically differentiated groups of ballan wrasse have been identified, north and south of Jæren, respectively, but little genetic differentiation was detected within these two groups (Seljestad 2019). Notably, a recent study found relatively low genetic divergence between wild goldsinny-wrasse populations in mid-Norway and populations in southern Norway and Sweden, suggesting low (but significant) genetic population structuring (Jansson et al. 2017). The structuring was more pronounced when non-neutral genetic markers (i.e., outlier loci) were also considered, suggesting that diversifying selection may be at play. This is of importance as directional selection on important life-history traits can maintain divergence at adaptive loci, whilst allowing other parts of the genome to reach a balance between homogenizing gene flow and diversifying random genetic drift (Lande 1976; Richter-Boix et al. 2011).

The genetic structure of wrasses is less known in the most relevant countries to import from; Sweden and Denmark. However, samples of corkwing, goldsinny, and ballan wrasses from Eastern Skagerak and Kattegat have been included in two studies (Faust et al. 2018; Jansson et al. 2017). None of these studies find evidence of a genetic difference from populations in Norwegian Skagerrak, but, as with the Norwegian Skagerrak samples, the Kattegat/Swedish Skagerrak samples are clearly differentiated from populations in Western Norway and northwards, especially for corkwing and ballan wrasses. To date, no study has included samples from of wrasses from the Baltic Sea or from the western coast of Denmark. Such knowledge is important to fully assess the consequences of cleaner fish translocation, as the differences in genetic composition between source and recipient populations have a major impact on the potential genetic changes resulting from such translocations.

### 1.6.7 Spread of species beyond their natural ranges

Invasion by non-indigenous species has long been recognized as a major threat to global biodiversity, second only to habitat loss and landscape fragmentation (Walker and Steffen 1997, Scalera et al. 2012).

There are two primary stages of invasion: The introduction, colonization, and establishment of a non-indigenous species into a new area (the introduced species must arrive, survive, and establish) and the spread and potential replacement/displacement of native species (or populations) by the introduced species.

Colonization by introduced species often involves a population bottleneck due to the initially small number of colonists. Hence, a newly established population is likely to be much less genetically diverse than the source population from which it derived. In addition, low genetic diversity in farmed fish, as a result of broodstock establishment based on a small number of individuals, may lead to a similar bottleneck and similar environmental consequence from escapees. There is a clear association between the greater number of introduced individuals and the number of release events and the likelihood of an introduced species becoming invasive, which suggests that many invasive species are not as genetically depauperate as expected (Allendorf and Lundquist 2003). Consequently, repeated escapes of cleaner fish, from potentially different sources, may impose an increased threat to locally adapted populations and species.

Examples of successful invasive colonization events are plentiful, and many introduced species often outcompete and replace native species. One example is the introduced brook trout (*Salvelinus fontinalis*), which causes serious problems in the western United States, where they often outcompete, and replace, ecologically similar species of native trout (Adams et al. 2000).

### 1.6.8 Other ecological hazards associated with the use of cleaner fish

The wrasse fisheries reduce the abundance and affect the size structure of goldsinny and corkwing wrasse in Skagerrak, while wider ecological consequences of the current fishing intensity remain uncertain (Halvorsen et al. 2017a). Common for all wrasses, is a very high site-fidelity of juveniles and adults, meaning that the scope for natural dispersal beyond the egg and larvae stage is limited. Effects of both fishing and translocations may thus be evident at small spatial scales (Villegas-Ríos et al. 2013; Skiftesvik et al. 2014a; Halvorsen et al. 2016b). All wrasses feed predominantly on immobile and slow-moving organisms, such as molluscs, gastropods, and small crustaceans, but considerable species, seasonal, and spatial differences have been reported (Alvsvåg 1993; Sayer et al. 1995, 1996; Deady and Fives 1995). They may thus influence the ecosystem to some degree as predators.

In salmon, competition between juveniles of wild and farmed origin may affect the genetic composition of wild salmon populations through cross breeding (Sundt-Hansen et al. 2015). Moreover, interbreeding between farmed fish and local wild populations has induced changes in life-history traits such as age and size of maturation (Bolstad et al. 2017). Similar effects could be expected in other fish species, where farmed and wild stocks encounter each other (Bolstad et al. 2017). Cleaner fish breeders are encouraged to select for increased cleaner-efficiency of the fish (Powell et al. 2018), which may further increase the difference between farmed and wild populations in the future.

#### *1.6.8.1 Introduction of other alien organisms through bycatch*

With the import of wild-caught cleaner fish there is a risk of spread of other species simultaneously. The highly invasive round goby (*Neogobius melanostomus,* "svartmunnet kutling") is native to the Black Sea / Caspian Sea region, and is spreading rapidly in Europe. The goby is now is established in Denmark and occurrences have been reported on the west coast of Sweden (Forsgren and Florin 2018). There is a potential risk that the round goby may be caught with wrasses in these areas and be transported, together with cleaner fish, to Norway (where, to date, it has not been recorded). The species is very adaptable and physically tolerant to different salinities, temperatures, and oxygen ranges. It is found in both marine/brackish systems as well as fresh water, although it hasn't yet been able to establish itself in conditions of full ocean salinity (Forsgren and Florin 2018). The species has the potential to spread to many different ecosystems, which it could affect in a range of ways, from being a food resource for local predators to competing with, and predating on, local species and resources, often very successfully (Forsgren and Florin 2018).

#### *1.6.8.2 Introduction of other alien organisms in transport-water*

The spread of species by ships and in ballast water around the world has been well known for centuries. As in transport with ballast water, organisms small enough, or those with a pelagic life stage, can be transported in the water that contains the cleaner fish being moved between areas. In contrast with ballast water, where the journey often is long, dark, and dirty, the transport of cleaner fish is fast and with optimal conditions for the fish. This may provide opportunities for more-sensitive species or life stages to spread beyond their natural ranges.

The Pacific oyster (*Magallana gigas,* syn. *Crassostrea gigas*) is a robust and adaptable mollusc that is already established in Norwegian waters (Jelmert et al. 2018). It is considered an invasive species with a very high risk of affecting local ecosystems (Jelmert et al. 2018). Currently found as far north as Nordmøre in central Norway, it is estimated to have the potential to spread to Nordland in northern Norway (Jelmert et al. 2018). Temperature is the most important factor controlling how far it will spread, as temperatures above 18° over 4-8 weeks are required for spawning. The pelagic larvae can remain in the water column for up to three weeks and the spawning period is normally in July-August (Nehring 2011). If the water used to transport cleaner fish from areas south of Nord-Møre were to be collected during the period July-September, and the fish and water transported further north, there is the potential for further and more-rapid spreading of the Pacific oyster.

Similarly, other species with pelagic life stages could potentially spread with the water used for transport of cleaner fish.

## 1.7 Factors influencing the risk associated with the use of imported cleaner fish

### 1.7.1 Escape rate

There is no publicly available documentation on the frequency and extent of escape of cleaner fish from salmonid aquaculture. However, statistics on escaped salmonids are available from the Directorate of Fisheries (https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Roemmingsstatistikk) and show that in 2019 so far 274,000 Atlantic salmon and 3,000 rainbow trout have escaped in 44 incidents. It has been suggested that the numbers of escaped fish could in fact be 2-4 times higher than reported (Skilbrei et al. 2015). Considering that there is 1-5 cleaner fish per 100 famed fish, this accumulates to a minimum of ~2,800 – 14,000 escaped cleaner fish. In larger incidents this could lead to a high propagule pressure on the local environment.

Guidelines for mesh size and minimum cleaner fish size (length) exist, but, for several reasons, it is assumed that escape of wrasses occurs relatively commonly. First, fishermen may deliver wrasse that are smaller than ordered. Under controlled settings it has been shown that 50% of commercially sourced goldsinny of Swedish origin escaped through the mesh, but the majority of these were smaller than 12 cm, which was the minimum size of the fish ordered (Woll et al. 2013). Second, it must be assumed that there is considerable individual, seasonal, and geographical variation in the condition and morphometry of the fish, allowing some fish to escape even when their length is greater than that suggested in the guidelines. Third, the mesh size in salmon pens is changed as the salmon grow; thus, if not all the wrasses are removed before the mesh size is changed, those remaining may have increased probability of escape. Fourth, cleaner fish are smaller than salmon and may be able to escape through even small tears or damage to the net pen.

The genetic change observed in native corkwing wrasse in Trøndelag (see 1.5.1.2) proves that escapes happen at a rate where the genetic composition of local populations is altered. As the number of cleaner fish escaping is a key factor influencing the level of risk associated with the use of imported cleaner fish, studies aimed at quantifying escape rates for the various species under different conditions and mesh sizes are highly warranted.

### 1.7.2 Breeding status

For wild-caught wrasse, there are species-specific minimum size limits that reflect that the size at maturity differ between species. For goldsinny wrasse, the legal size limit is 11 cm, but as goldsinny wrasse mature before reaching 10 cm, all those being used can, potentially, be ready to breed. Goldsinny is a broadcast spawner and has pelagic eggs, so it is likely that spawning happens inside sea-cages. If so, fertilized eggs from translocated goldsinny may drift and hatch among local populations. This means that measures that prevent the escape of adult goldsinny wrasses may reduce, but not eliminate, the risk of compromising local genetic structure. Corkwing wrasses also mature at sizes smaller than the minimum size limit of 12 cm (Halvorsen et al. 2016a), but as they require a hard substratum and access to specific algae species for nesting and they provide parental care, spawning inside the sea cages is unlikely to happen. The size limit for ballan wrasse is 14 cm, and the fish mature at 18 cm or larger (Darwall et al. 1992). Ballan wrasse is also a nesting species with benthic eggs, suggesting that in-cage spawning for this species is unlikely. All three species spawn from May to the beginning of July, with the timing of the onset and duration probably dependent on temperature (Skiftesvik et al*.* 2014; Halvorsen et al. 2016b).

### 1.7.3 Time of introduction

In Norway, the Institute of Marine Research surveyed the duration of the spawning period in different regions between 2013 and 2018. Based on the results of this survey, the

Directorate of Fisheries set the opening date of the fishery to 17th July south of Stadt and 31st July north of Stadt. In 2019, the Norwegian fishery will close on the 20th October. In Sweden, the fishery opens on 15th May. Therefore, the import and subsequent escape of ready-to-spawn wrasse from Sweden during the spawning season can increase the probability of genetic change of local populations. When import occurs after the spawning period, the risk of in cage-spawning for goldsinny is minimized, and any wrasse escaping would have to survive the winter in order to spawn. This would probably reduce the risk and extent of genetic change. The number of wrasses imported from Sweden and the time of their import are shown in Figures 1.4.4.2-2 and 1.4.4.2-3 for south and north of Stadt, respectively.

### 1.7.4 Source (origin)

Although most marine populations are thought to be well connected through long-distance dispersal of larvae, the examples of isolation-by-distance (IBD) are plentiful. As a result, the larger the distance between the source and the recipient populations, the greater is the chance of mixing genetically distinct individuals. In addition, larvae are not necessarily passive particles, and several mechanisms (such as vertical migration, limited circulation, and parental care) could limit larval dispersal. Such mechanisms, combined with potential homing behaviour in adult fish, could enhance the potential for genetic structuring, increasing with physical distance. In addition, physical barriers or currents may inhibit migration also at a much smaller scale, causing genetic structuring also at a small spatial scale.

### 1.7.5 Transportation

Based on information from transport companies, wrasses are imported from Sweden by trucks, but are not mixed with Norwegian wrasses in the trucks during transportation. However, no publicly available documentation exists. In general, the transport companies report that transport time is minimized to avoid stress, injuries, and mortalities of the fish that are transported in high densities and with no possibility of water exchange.

### 1.7.6 Destination

The risks associated with importing cleaner fish to Norway are strongly dependent on the region of destination. Wrasse populations in western- and central Norway are more genetically different from Swedish and Danish populations (see 1.5.1.2, 1.5.2.2, and 1.5.3.2) compared to populations in southern Norway. Moreover, wrasses deployed in Northern Norway can, potentially, escape and establish north of their natural distribution range.

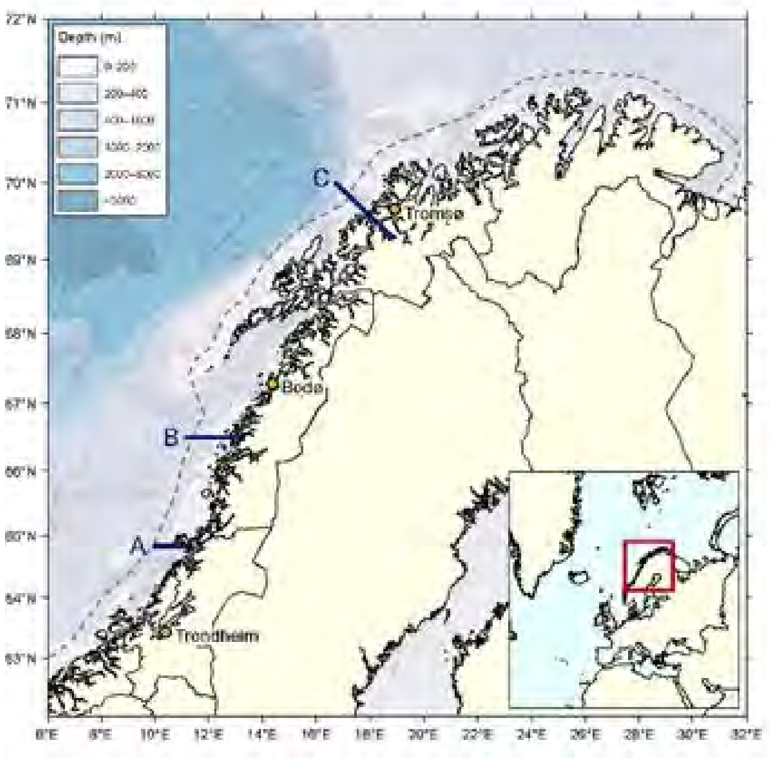


**Figure 1.7.6-1:** Northern natural geographical limits for (A) corkwing wrasse (N 64°50.3’), (B) ballan wrasse (N 66°30’), and (C) goldsinny wrasse (N 69°29.4’).

A coastal fyke-net survey conducted by the Institute of Marine Research investigated the northern limit of the relevant wrasse species, (Figure 1.7.6-1, K. Nedreaas, unpublished data). These reports have also been checked against species observations reported by citizens to the Norwegian Biodiversity Information Centre (www.biodiversity.no).

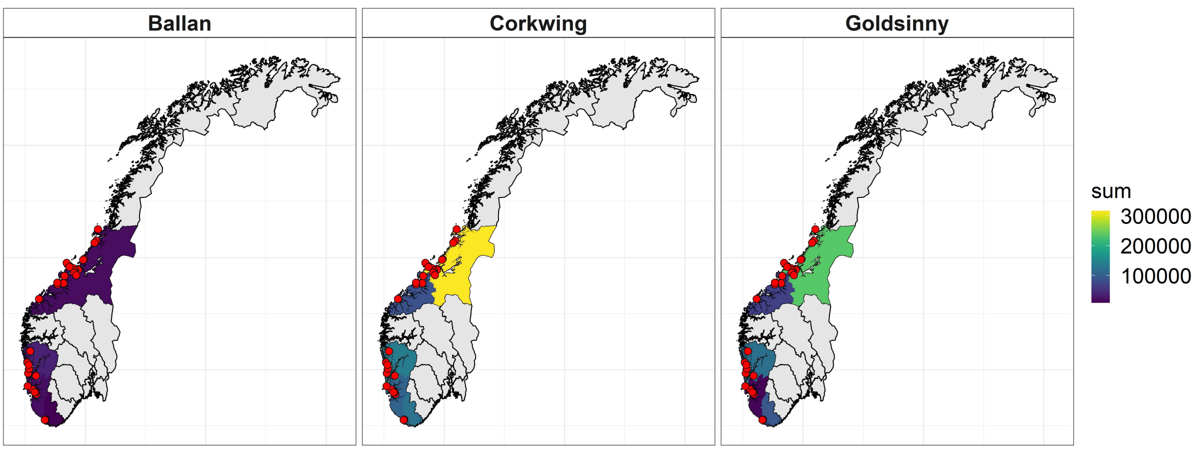


**Figure 1.7.6-2:** Numbers of imported wrasses (in total) from Sweden in 2017 and 2018, shown for each county and species. Dots indicate where the aquaculture facilities are located.

Figure 1.7.6-2 show the location of all aquaculture facilities that received imported cleaner fish from Sweden in 2017 and 2018 (red dots). It also depicts how many individuals of each species that was imported to each county these years in total. Compared to the northernmost distribution of the three most relevant species (Figure 1.7.6-1), this is important information for assessing the probability of spread beyond their natural distribution.

### 1.7.7 Complexity of parasite lifecycles

There is a higher risk from introducing novel host-specific parasites with direct lifecycles (no intermediate host) than generalist parasites with several hosts in their lifecycle. Parasites with a direct lifecycle can, under certain circumstances, become very numerous within a short period and cause disease and mortality in a host population. Disease outbreaks caused by parasites with many hosts in their lifecycle are largely dependent on the presence and density of the other hosts. On the other hand, the introduction of novel parasites with multiple hosts in their lifecycle may have significant negative consequences for the other host species in the lifecycle, even if the consequences for the fish host are considered negligible.

### 1.7.8 Incubation time of infectious agents

The incubation time from when infection occurs until manifestation of clinical disease may vary significantly among infectious agents. This means that the likelihood that a carrier status may be detected during quarantine periods will also vary, and depend upon the duration of the quarantine. Moreover, many (likely most) recognised pathogens will also depend, to some extent, on the resilience of the host in terms of their ability to cause disease and may not necessarily result in a clinical manifestation until the host is otherwise compromised (stressed, immunocompromised, wounded, etc.). The presence of subclinical carriers has, for example, been suggested as a likely contributing factor for the high prevalence of *A. salmonicida* outbreaks observed amongst wrasse used as cleaner fish in Norway (Gulla et al. 2016).

# 2 Methods and data

## 2.1 Methodology for risk assessment

We have chosen to use a semi-quantitative risk assessment, where, as judged by the group of experts, overall risk is the product of the magnitude of the consequences of the event multiplied by the likelihood that the event will occur.

The results are presented in figures such as that of Figure 2.1-1.

The probability of disease transmission or environmental effects is a function of time and of the volume of cleaner fish. Thus, the risk from the negative environmental effects increases relative to the number of imported cleaner fish introduced. There are also much uncertainty associated with the number of fishes expected to escape, the status (absence/presence/density) of local populations of the three different wrasse species considered, as well as of the previous presence of pathogens in the local environments.

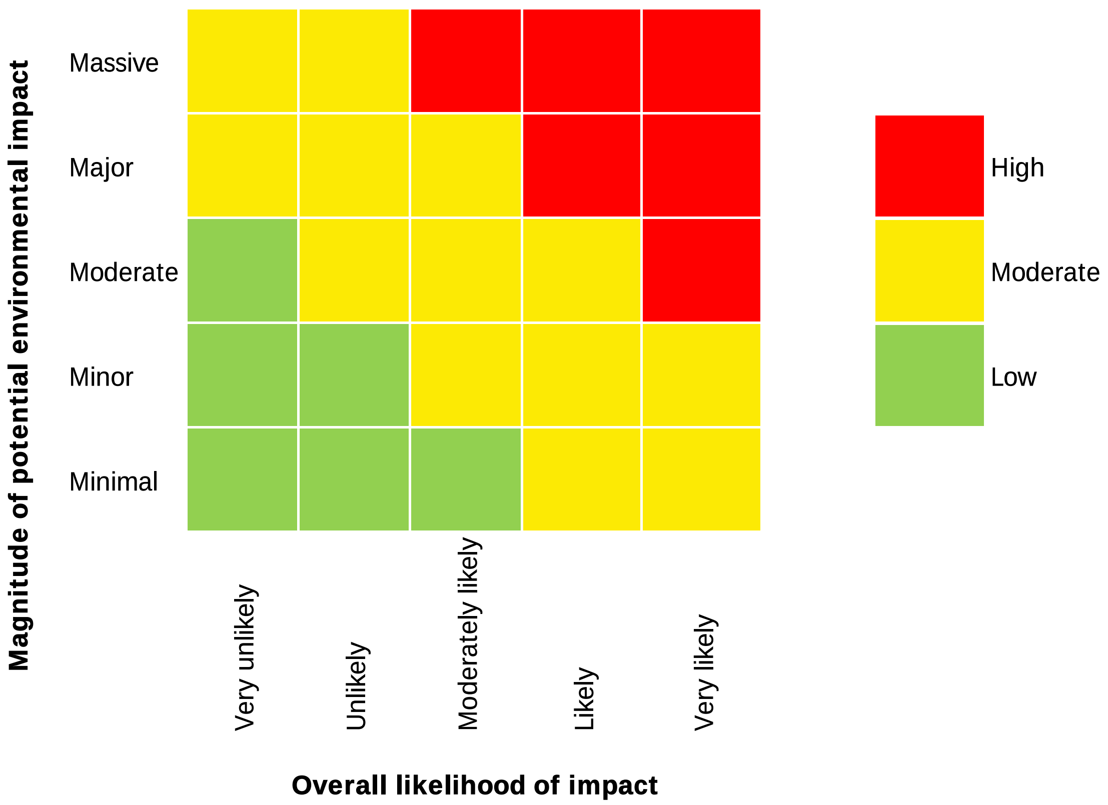


**Figure 2.1-1:** The conclusion of the risk assessments (Low, Moderate, or High) are based on the overall likelihood of the impact and the magnitude of the potential consequences of that impact on Norwegian biodiversity.

In order to provide clear justification of when a particular rating is given in the risk assessment template, the Panel used ratings and adapted versions of the descriptors from

Appendix E in (EFSA Panel on Plant Health (PLH) 2015). A description of the ratings used can be found in Tables 2.1-1 – 2.1-3 below.

**Table 2.1-1** Ratings used for the assessment of the magnitude of the impact.

| Rating | Descriptors |
|---|---|
| **Minimal** | No known impact on local biodiversity |
| **Minor** | Potential impact on local biodiversity, but only occasional deaths of individuals |
| **Moderate** | Impact may cause moderate reduction in viability and adaptability of native populations |
| **Major** | Impact may cause severe reductions in local populations with consequences for local biodiversity and ecosystem functions and services |
| **Massive** | Impact may cause severe reductions in local biodiversity (local extinctions), with severe consequences for ecosystem functions and services |

**Table 2.1-2** Ratings used for the likelihood of impact.

| Rating | Descriptors |
|---|---|
| **Very unlikely** | Negative consequences would be expected to occur:<br>• once per decade, or<br>• with a likelihood of 0-5% per 1,000,000 imported fish |
| **Unlikely** | Negative consequences would be expected to occur:<br>• a few times per decade, or<br>• with a likelihood of 5-25% per 1,000,000 imported fish |
| **Moderately likely** | Negative consequences would be expected to occur:<br>• once per year, or<br>• with a likelihood of 25-65% per 1,000,000 imported fish |
| **Likely** | Negative consequences would be expected to occur:<br>• a few times per year, or<br>• with a likelihood of 65-95% per 1,000,000 imported fish |
| **Very likely** | Negative consequences would be expected to occur:<br>• Six or more times year, or<br>• with a likelihood of 95-100% per 1,000,000 imported fish |

**Table 2.1-3** Ratings used for describing the level of confidence

| Rating | Descriptors |
|---|---|
| **Very low** | There is very little or no published data on the topic. Only expert judgement used. |
| **Low** | Available information on the topic is limited, and mostly expert judgements are used. |
| **Medium** | Some published information exists on the topic, but expert judgements are still used. |
| **High** | There is sufficient published information, and expert judgements are in concurrence. |
| **Very high** | The topic is very well debated in peer-reviewed journals, and international reports. Expert judgements are in concurrence. |

## 2.2 Literature search

Literature searches were conducted from February to August 2019 through the Web of Science (https://clarivate.com/products/web-of-science/) and Google scholar. Search terms used in Title/Abstract fields included “cleaner fish” “wrasse” “lumpfish” “infectious agents” “genetic” “distribution” “spread” “bacteria” “parasites” “viruses” “introgression” “populations”. Search strings were built using Boolean operators AND and OR. Full texts for articles of potential relevance were assessed to determine their relevance to this report. The reference lists in the selected articles formed the basis for identifying additional articles or reports within the topics listed in the terms of reference, overlooked by the searches. Additionally, individual searches were performed as needed on topics not directly related to cleaner fish in salmonid aquaculture. Articles were excluded if they did not relate to the terms of reference. Articles that were not in English, or a Scandinavian language (Swedish, Danish, and Norwegian) were also excluded.

## 2.3 Other literature

In addition to published scientific papers, important sources of information for this project have been reports on the subject from the Institute of Marine Research (Harkestad et al. 2010; Halvorsen et al, 2017; Skiftesvik et al. 2017, 2018) the Norwegian Veterinary Institute (Nilsen et al. 2014; Hjeltnes et al. 2018) and the risk assessment of fish health associated with the use of cleaner fish in aquaculture published by VKM in 2017. The master theses by Askeland, J. (2002) and Seljestad, G.W. (2019) from the University of Bergen have also provided relevant information. The reference lists in in those reports and theses were scrutinized to identify additional articles or reports.

## 2.4 Distribution data

Data used to map the distribution of the respective species originate from Institute of Marine Research (HI), and was downloaded from Geonorge.no. All data was handled in R Core Team (2013) and ggplot2 (Wickham 2016) was used for plotting.

## 2.5 Import data

The data on imported wrasses from Sweden (Figures 1.4.4.2-2 and 1.4.4.2-3) contained information on 501 consignments in the period 2017–2018, provided by the Norwegian Environmental Agency. In addition to information on species, the number of fish in each consignment and municipality, county, and coordinates of each importer were included in the consignment information. However, several entries contained the wrong year of export, either in the past (1988) or in the future (2019). After removing erroneous data points 306 entries were used for plotting. This information was also used to map the imports in Norway (Figure 1.7.6-2).

# 3 Hazard identification

## 3.1 Relevant source areas for import of species used as cleaner fish in Norway

### 3.1.1 Wild-caught wrasses (*S. melops, L. bergylta,* and *C. rupestris*)

This report focuses on the risk from importing the wrasse species, from other countries, that are already established as cleaner fish in Norwegian aquaculture. To date, Sweden and Denmark are the only relevant sources for import. However, wrasses are being caught in the United Kingdom to be used as cleaner fish in salmon farms on the British Isles, and, although these will predominantly be used there, requests for import from the British Isles cannot be ruled out in the future. However, in the current situation, imported wrasses are transported by trucks, and the transport time is a key factor affecting the welfare and quality of cleaner fish, reducing the likelihood of establishment of longer transport routes. Other wrasse species, such as *Coris julis* and *Symphodus bailloni*, are distributed from the English Channel and southwards. However, these are adapted to warmer waters and it is unlikely that that they would thrive as cleaner fish in Norway today. These species are therefore not assessed in this risk assessment. A new risk assessment will be needed should wrasse species not naturally occurring in Norway be relevant for import as cleaner fish.

### 3.1.2 Farmed wrasses

Ballan wrasse is currently the only wrasse species that is being cultured as a cleaner fish. For both goldsinny and corkwing, successful small-scale trials were conducted in the 1990s, but have not been pursued at a commercial scale, probably due to the greater availability and lower price of wild-caught individuals of these species. It remains unlikely that commercial-scale culture will be initiated in the future for the same reasons. Cultured ballan wrasse is being produced and used in Scotland. Two Scottish producers, Marine Harvest Scotland and Scottish Sea Farms, have reported to be the first to have managed to close the production cycle of ballan wrasse, thus using captive-bred broodstock. This advantageous development could potentially increase production and it is not unlikely that there might be an incentive to import cultured ballan wrasse from Scotland in the future due to the unfulfilled demand in Norway.

### 3.1.3 Lumpfish (*C. lumpus*)

Lumpfish are considered less challenging to produce, easier to obtain, and its production cycle is nearly 60% shorter than that of ballan wrasse (Brooker et al. 2018). Commercial production of lumpfish has increased exponentially in recent years, with nearly all lumpfish coming from wild broodstock (Powell 2018). Norway and Iceland are the biggest producers of lumpfish eggs, supplying most lumpfish used as cleaner fish in Scotland, Ireland, and the Faroe Islands (Whittaker et al. 2018). Although having a wide natural range, lumpfish have five genetically distinct groups, also with phenotypic differences, suggesting that transfer across these groups should be avoided (Whittaker et al. 2018). As with ballan wrasse, closing the breeding cycle in captivity and, ideally, producing sterile lumpfish for use as cleaner fish is highly desirable (Whittaker et al. 2018), but has not yet been achieved. If this is achieved elsewhere, import of lumpfish may be requested.

## 3.2 Potential hazards related to import of specific cleaner-fish species to Norway

### 3.2.1 Genetic changes in local populations of cleaner fish

Import of cleaner fish with a different genetic origin than the native population may lead to genetic alterations in native populations, either through in-cage spawning, where fertilized eggs drift out and settle in the surroundings, or through escape and subsequent spawning with native fish. The former is only likely to be the case for goldsinny wrasse, which is a broadcast spawner, as ballan wrasse, corkwing wrasse, and lumpfish are nesting species where the survival of eggs depend on paternal care. Import during the spawning period increases the likelihood of in-cage spawning and successful spawning of escapees. Further, the amount of genetic change in native populations will depend on the following factors:

- the genetic and phenotypic differences between imported and native cleaner fish;
- the age at spawning relative to age at import;
- the number of fertilized eggs produced by imported fish in-cage;
- the number of imported fish escaping, surviving, and successfully spawning;
- the effective and census population sizes of the native population;
- the survival/fitness of hybrid offspring;

### 3.2.2 Spread of species beyond their natural ranges

#### *3.2.2.1 Wild wrasses*

The three wrasse species of relevance differ in their northern distribution (Figures 1.5.1.1-1, 1.5.1.2-1, 1.5.1.3-1). Corkwing wrasse has the southernmost range edge, but it has been expanding northwards in recent decades (Faust et al. 2018), reaching the southern border of Nordland. Ballan wrasse has been found halfway up the Nordland coast, and goldsinny occur as far north as Tromsø. If imported wrasses are released north of their natural range edge, individuals may escape and establish, and become regionally introduced species. A prerequisite for establishment of a breeding population is that the local density is high enough to allow wrasses to find mates (other escapees). Hence the probability of such establishment depends strongly on the number of fish translocated north of the natural range, in addition to the spatial distribution of these translocations.

#### *3.2.2.2 Lumpfish (C. lumpus)*

Lumpfish are widely distributed in the North Atlantic (see 1.5.4.1). Thus, spread of this species beyond its natural distribution through import for use in aquaculture, is not relevant here.

### 3.2.3 Transfer of novel infectious agents to Norway

A multitude of various infectious agents that infect wrasses and other fish species can be spread by wrasses (both farmed and wild caught) and lumpfish imported for use as cleaner fish. See chapters 1.6.1 – 1.6.4 for an overview. Although fungal pathogens (see 1.6.5) may be transported along with the imported cleaner fish, there is no documentation of relevant examples of fungal pathogens that are not already present in Norwegian waters. Therefore, fungal pathogens have not been assessed any further.

#### *3.2.3.1 All relevant wrasses*

For import of wrasses from relevant areas, the project group has chosen to focus their risk evaluation on the selected infectious agents listed below. These have been chosen based on their published occurrences within and outside Norway.

Parasitic pathogens of special concern:

- *Microcotyle donavini* (see Table 1.6.1-3)
- *Macvicaria alacris* (see Table 1.6.1-3)
- *Gaevskayatrema perezi* (see Table 1.6.1-3)

These three selected parasites, one monogenean and two digeneans, have so far not been described from Norwegian wrasses but are present in areas south of Norway.

Viral pathogens of special concern:

- NNV (see 1.6.3.1)
- VHSV (see 1.6.3.2)
- SAV (see 1.6.3.8)

Of the bacterial pathogens, only *Aeromonas salmonicida* (see 1.6.2.1) is considered to pose a risk due to the geographical limits set by relevant areas of import (see 3.1.1).

#### *3.2.3.2 Lumpfish (C. lumpus)*

Regarding import of lumpfish, the project group has chosen to focus the risk evaluation on the infectious agents listed below. These have been chosen based on the published occurrences within and outside Norway. No parasites were assessed as being relevant to include in relation to import of lumpfish, as all known parasites of lumpfish already occur in Norway.

Bacterial pathogens of special concern:

- *Aeromonas salmonicida* (see 1.6.2.1)
- *Pasteurella skyensis* / *Pasteurella* sp. (see 1.6.2.6)
- *Piscirickettsia salmonis* (see 1.6.2.7)

Viral pathogens of special concern:

- VHSV (see 1.6.4.1)
- Lumpfish ranavirus (see 1.6.4.3)

### 3.2.4 Other ecological hazards of import in general

#### *3.2.4.1 Introduction of other alien organisms through bycatch*

As a threshold species, the round goby (*Neogobius melanostomus)* is, by definition, expected to arrive in Norwegian waters during the next 5-10 years. There is a potential that round gobies may be caught with wrasses and transported to Norway (where it has not, to date, been recorded). The species is very adaptable and physically tolerant to different salinities, temperatures, and oxygen ranges. It is found in both marine/brackish systems, as well as fresh water, although, it is not yet established in conditions of full ocean salinity (Forsgren and Florin 2018). Although expected to occur in our waters in the future through normal migration, an accidental introduction straight up to Trøndelag from Denmark/Sweden would be unfortunate.

#### *3.2.4.2 Introduction of other alien organisms in transport water*

The Pacific oyster serves as an example of organisms spreading through ballast water and it is not unlikely that most organisms with a pelagic life stage, both flora and fauna, could accompany the transport water for cleaner fish. As the journey is fast and the conditions are good, many organisms would be expected to survive the journey, if left untreated.

## 3.3 Hazard identification in a 50-year perspective

In a 50-year perspective, with cleaner fish escaping over consecutive years, the genetic effects would be expected to accumulate with both time and with increasing numbers of imported fish.

Climate modelling indicates warmer winters in Norwegian waters over the next fifty years. This is based on global climate models from the Intergovernmental Panel on Climate Change (IPCC 2013) downscaled for an oceanic area covering the entire Norwegian coast (Hanssen-

Bauer et al. 2015). The climate data covers the period 1960-1990 and towards year 2068 under the $CO_2$ emission scenarios RCP4.5 (emission peak 2040-2050, then decline) and RCP8.5 (business as usual). Use of scenario RCP8.5 has been recommended by the Norwegian Biodiversity Information Centre (Sandvik et al. 2015). The ocean climate of the Norwegian Sea and the Barents Sea is largely determined by the inflow of Atlantic water. In addition, the climate along the Norwegian coast depends on regional wind conditions and freshwater runoff. A temperature increase of about 1 °C is estimated for the Barents Sea, and a somewhat larger increase is estimated for the North Sea. The ocean's large heat capacity leads to far-less temperature variation than in the atmosphere. Additional expected effects of climate change are acidification and sea level rise. Due to increased $CO_2$ uptake, the pH of the ocean surface is estimated to be reduced by about 0.2 between 2000 and 2065. Measurements from recent decades indicate that sea-level rising has accelerated significantly and is predicted to increase by 15 - 55 cm, depending on location, along the Norwegian coast.

Climate change can be expected to influence the northern distribution limit of the species, the timing of spawning, and the composition of the ecosystem (e.g. the food network and the presence of parasites and other infectious agents). Ongoing rises in sea temperature will allow non-native species to populate ocean habitats in niches that were once outside the temperature range of the species. However, it is difficult to predict which species will become invasive.

# 4 Hazard characterization

## 4.1 Potential consequences related to import of specific cleaner-fish species to Norway

### 4.1.1 Potential consequences of genetic changes in local populations

The most extreme genetic consequence of introduction of imported cleaner fish is that local populations can go extinct through displacement by the introduced fish or through complete interbreeding between the introduced fish and the local populations. In less-severe cases, the local population may be reduced or demographically changed (e.g. changes in gender ratios) and thereby lose genetic variability. If the genetic diversity of the imported fish is significantly lower, or very different from, than that of the wild populations, hybridization will also lead to diversity loss. Diversity loss may result in decreased adaptability to environmental changes. Finally, the local population may become less fit after hybridization through breakdown of locally adapted genotypes or the spread of less-favourable genotypes from the introduced population (outbreeding depression).

#### *4.1.1.1 Corkwing wrasse (S. melops)*

The corkwing wrasse has strong genetic structuring, both within Norway and within Scandinavia (see 1.5.1.2). It is a nest-building species with benthic eggs, and thus natural gene flow between populations is restricted. Genetic change from breeding between local and translocated fish has been demonstrated in Trøndelag.

The project group assessed the potential consequence of imported corkwing wrasse causing genetic change in local populations of *S. melops* to be major, with medium confidence. There are documented strong genetic differences between corkwing wrasse populations to the north and to the south of Jæren in Norway. This genetic break aligns with clear differences in life-history traits, such as growth rate, maturation, and life span (Halvorsen et al. 2016a). Thus, it is likely that genetic changes due to translocation could lead to spreading of maladaptive genotypes that could reduce resilience or adaptability, especially for populations found at the leading edge in a range-expanding species, like the corkwing wrasse (Faust et al. 2018).

#### *4.1.1.2 Ballan wrasse (L. bergylta)*

The ballan wrasse has strong genetic structuring of the populations, both within Norway and within Scandinavia (see 1.5.2.2 and 1.6.6). It is a nest-building species with benthic eggs and thus natural gene flow between populations is restricted.

The project group assessed the consequence of imported ballan wrasse causing genetic changes in local populations of *L. bergylta* to be major, with low confidence. There are documented strong genetic differentiation between ballan wrasse populations to the north and to the south of Jæren in Norway (including all of Skaggerak) (Seljestad 2019). Thus, it is likely that genetic changes due to translocation could lead to the spread of maladaptive genotypes that could reduce resilience or adaptability.

#### *4.1.1.3 Goldsinny wrasse (C. rupestris)*

The goldsinny shows a pattern of isolation by distance along the Norwegian coast (see 1.5.3.2). Its reproductive cycle includes a pelagic egg stage, which may facilitate dispersal over larger distances. Genetic exchange between goldsinny with southern Scandinavian origin and local populations in Trøndelag has been suggested.

The project group assessed the consequence of imported goldsinny causing genetic change in local populations of *C. rupestris* to be moderate, with medium confidence.

#### *4.1.1.4 Lumpfish (C. lumpus)*

Little genetic structuring has been found in lumpfish along the Norwegian and Swedish coasts, although significant genetic differences have been found at larger spatial scales (see 1.5.4.2). The eggs undergo paternal care throughout the incubation period, and, after hatching, the larvae attach to the substrate. These factors probably limit larval dispersal.

The project group assessed the consequence of imported lumpfish causing genetic changes in local populations of *C. lumpus* to be moderate, with medium confidence.

### 4.1.2 Potential consequences following spread of the cleaner-fish species beyond their natural ranges

When a species establishes in a new environment, the natural control mechanisms keeping its population numbers in balance within its current range will be absent. This will affect the ecosystem where it establishes (by consuming native species, competing with them for food or space, or introducing disease) and may lead to loss of biodiversity. The cleaner-fish species relevant for import, and hence considered in this report, are all native to Norway, but they may be introduced north of their current distribution range.

#### *4.1.2.1 Corkwing wrasse (S. melops)*

Corkwing wrasse would, if spread further north due to its use in aquaculture, end up in a similar habitat as that which it currently inhabits. 'There is no documentation showing that it would displace or threaten other species occupying its niche, and it is not known to have a negative impact on the environment. Corkwing wrasse is currently undergoing a natural range shift, extending its northward distribution (Knutsen et al. 2013), even documented on a decadal scale (Faust et al. 2018). Hence, the project group conclude that it is most likely that a natural northward-expansion will continue as temperatures are expected to increase, which would gradually limit the scope of spreading this species beyond the northern limit within Norway. The project group therefore assessed the consequences following spread of *S. melops* beyond its natural range to be minor, with low confidence. The only potentially negative effect would be related to genetic changes in local populations, if the northernmost population later spreads to this area and mates with the artificially established population with a different genetic background (see 1.6.7)

#### *4.1.2.2 Ballan wrasse (L. bergylta)*

Ballan wrasse would, if spread further north due to use in aquaculture, end up in a habitat similar to that which it currently inhabits. There is no documentation showing that it would displace or threaten other species occupying its niche, and it is not known to have a negative impact on the environment. It is found further north than the corkwing wrasse, halfway up the Nordland coast (66.5 N). The project group therefore assessed the consequences following spread of *L. bergylta* beyond its natural range to be minor, with low confidence. The only potentially negative effect would be related to genetic changes in local populations, if the northernmost population later spreads to this area and mates with the artificially established population with a different genetic background (see 1.6.7)

#### *4.1.2.3 Goldsinny wrasse (C. rupestris)*

Goldsinny wrasse is sparsely distributed up to (69.5° N) and it is not likely that the species will spread further north due to its use in aquaculture. The project group therefore assessed the consequences following spread of *C. rupestris* beyond its natural range to be minor, with low confidence. The only potentially negative effect would be related to genetic changes in local populations, if the northernmost population later spreads to this area and mates with the artificially established population with a different genetic background (see 1.6.7)

#### *4.1.2.4 Lumpfish (C. lumpus)*

Lumpfish is naturally distributed along the entire Norwegian coast, so spread to new areas following its use in aquaculture is not relevant. However, potentially negative effects could be related to genetic changes in local populations (see 4.1.1.4). The project group therefore assessed the consequences following spread of *C. lumpus* beyond its natural range to be minor, with low confidence.

### 4.1.3 Potential consequences from transfer of novel infectious agents to Norway

Research activity on infectious diseases in the four cleaner-fish species is heavily biased in favour of specimens used for salmon delousing, particularly in Norway. Limited information exists regarding the infection status of wild populations both within and outside Norway. No major infectious diseases in cleaner fish have been documented exclusively outside of Norway. Nevertheless, the possibility of existence of hitherto-unknown cleaner fish pathogens, in the form of either undescribed species or variant high-virulent strains, cannot be disregarded and could represent a significant concern. Variations in terms of host susceptibility across geographically separate cleaner-fish populations is also possible, and several cases exemplify how infectious agents that have been of limited importance in their native environment, may result in mass deaths in naïve host populations. This includes VHSV in The Great Lakes in US (Stepien et al. 2015) and *Gyrodactylus salaris* in Norway (Bakke et al. 2004).

#### *4.1.3.1 All relevant wrasse species*

The project group assessed that the potential consequences to Norwegian biodiversity following introduction and spread of the selected infectious agents would be:

- Moderate, with medium confidence, for *Microcotyle donavini.* This egg-laying monogenean flatworm occurs on the gills of its host and has a one-host lifecycle. It feeds on epithelial cells and blood, and, when numerous, may affect the health of the host significantly.
- Minimal, with medium confidence, for *Macvicaria alacris.* This trematode occurs as preadults and adults in the digestive tract of the fish host and affects the health of its definitive host to a limited extent. The intermediate hosts in the lifecycle are unknown.
- Minimal with medium confidence for *Gaevskayatrema perezi.* This trematode occurs as preadults and adults in the digestive tract of the fish host and affects the health of its definitive host to a limited extent. The intermediate hosts in the lifecycle are unknown.
- Minimal, with low confidence, for NNV. This virus is widespread among many marine fish species and has been detected in cleaner-fish species in Norway (Korsnes et al. 2017).
- Major, with high confidence, for VHSV. This virus is widespread among many marine fish species in the North Sea/ Baltic Sea and is, potentially, very pathogenic (Sandlund et al. 2014).
- Minor, with low confidence, for SAV. This virus causes PD in farmed Atlantic salmon and rainbow trout. The disease is very widespread in the southern part of the farming area (i.e., in the area where salmon-louse treatment, including the use of cleaner fish, is most intense).
- Moderate, with medium confidence, for *Aeromonas salmonicida*. While this bacterial species is widespread in Norway (including in wrasse), multiple subtypes with apparently discrete host preferences have been verified worldwide from various fish species. Introduction of subtypes exotic to Norway may pose a threat towards local wrasse populations.

#### *4.1.3.2 Lumpfish (C. lumpus)*

The project group assessed that the potential consequences to Norwegian biodiversity following introduction and spread of the selected infectious agents would be:

- Major, with high confidence, for VHSV. This virus is widespread among many marine fish species in the North Sea/ Baltic Sea and is also, potentially, very pathogenic (Sandlund et al. 2014).
- Minor, with low confidence, for lumpfish ranavirus. Ranaviruses are common infections in many poikilothermic animals, including fish. Some ranaviruses are particularly pathogenic to fish, i.e., the ranavirus EHNV.
- Moderate, with medium confidenc,e for *Aeromonas salmonicida.* While this bacterial species is widespread in Norway (including in lumpfish), multiple subtypes with apparently discrete host preferences have been verified worldwide from various fish species. Introduction of subtypes exotic to Norway may pose a threat towards local lumpfish populations.
- Minor, with low confidence, for *Pasteurella skyensis* / *Pasteurella* sp. Existing as a significant lumpfish pathogen in Norway is a close relative of the (thus far) UK-exclusive salmon pathogen, *Pasteurella skyensis*. It remains unclear from available literature, however, whether reported *Pasteurella* infections in British lumpfish have been caused by strains similar to the one found in Norway.
- Minor, with low confidence, for *Piscirickettsia salmonis.* Putatively low-virulence strains already exist in Norwegian waters, but have never been found in Norwegian lumpfish. It remains unknown whether a strain recovered from Irish lumpfish in 2017 represents a potentially significant lumpfish pathogen.

### 4.1.4 Potential consequences of other ecological hazards from import of cleaner fish in general

All transport of live animals is associated with some risk related to the introduction of both alien organisms and infectious agents. In the case of fish transportation, we also need to consider the water within which the fish are transported.

#### *4.1.4.1 Introduction of alien organisms through bycatch*

As all wrasses currently imported are wild caught (see 1.4.4.2), other fish will inevitably also be captured as bycatch. The project group has identified the round goby (*N. melanostomus*) as a potential hazard that could be introduced through bycatch when sourcing wrasses for use as cleaner fish in aquaculture. See 1.6.8.1 for more information on this highly invasive species. The project group assessed that the potential consequences for biodiversity in Norway following introduction of the round goby through bycatch to be major, with high confidence.

#### *4.1.4.2 Introduction of alien organisms in transport-water*

A wide range of micro-, and small macro-organisms may occur in the water used to transport the cleaner fish. This includes various infectious agents (viral, bacterial, and parasitic), harmful algae, alien crustaceans, and invasive molluscs. Although already present in some areas in Norway, the Pacific oyster (*M. gigas* syn. *C. gigas*) is highlighted by the project group as an example of an invasive species with a high impact on local biodiversity (see 1.6.8.2), which could be introduced to new areas with water used to transport cleaner fish. The project group assessed that the overall consequences stemming for this type of organism to be moderate, with low confidence.

## 4.2 Possible consequences in a 50-year perspective

Any hybridization events occurring between imported cleaner fish escaping from salmon farms and local populations of wrasses or lumpfish may have long-term consequences. However, the severity is expected to increase with repeated interbreeding (new escapees) and backcrossing over 50 years.

Several factors related to climate change (see section 3.3) could potentially contribute to negative consequences of imported cleaner fish, but these are impossible to predict with any accuracy. The northern limit of the distribution range will be affected by increased ocean temperature, but we assume that the contribution of imported cleaner fish will be minimal compared with that of natural migration and spread of cleaner fish already in Norwegian waters.

The expert group assessed the possible negative consequences of release of imported cleaner fish in a 50-year perspective to be moderate, with medium probability.

# 5 Exposure / Likelihood

## 5.1 Likelihood of negative impacts related to import of specific cleaner-fish species to Norway

### 5.1.1 Likelihood of genetic changes in local populations

Assessing the likelihood that import of cleaner fish will result in genetic changes in local populations relies on several aspects of the species biology (distribution and genetic structuring (see 1.5)) and life-history traits, like spawning behaviour (nest building or open-water spawning). It also depends on the extent of the import (in terms of number of fish (see 1.4.4)), whether the import occurs before or after spawning in the local populations, and the age of the imported fish. Finally, escape rate and potential release will also affect the likelihood. Importantly, these assessments also rest on the assumption that, as dictated by current legislation, cleaner fish are not released into the local environment after use (See 1.3.4).

#### *5.1.1.1 Corkwing wrasse (S. melops)*

Corkwing wrasse is one of the top-two most-imported cleaner-fish species, and 150,000 individuals have been imported annually from Sweden for the last couple of years (see Figures 1.4.4.2-2 and 1.4.4.2-3). However, most of the fish are imported after the main spawning season has ended in Norway. Also, these spawn in nests built by the males, and this reduces the likelihood of spawning occurring in the salmon cages.

The project group assessed that the likelihood of negative effects on biodiversity in Norway, in terms of genetic changes in local populations, as a result of import of *S. melops* as being moderately likely, with high confidence.

#### *5.1.1.2 Ballan wrasse (L. bergylta)*

Import of ballan wrasse is not extensive compared to Norwegian landings, and only around 50,000 individuals have been imported annually from Sweden during the last couple of years (see Figures 1.4.4.2-2 and 1.4.4.2-3). However, most of the those that are imported arrive before the main spawning season has ended in Norway, which greatly increases the likelihood of mating, should they escape. Ballan wrasse is, however, larger than the other two species, which decreases the likelihood of escape. Also, as with the corkwing wrasse, ballan wrasses spawn in nests built by the males, and this reduces the likelihood of spawning in the salmon cages.

The project group assessed that the likelihood of negative effects on biodiversity in Norway, in terms of genetic changes in local populations, as a result of import of *L. begylta* as being unlikely, with high confidence.

#### *5.1.1.3 Goldsinny (C. rupestris)*

Along with corkwing wrasses, goldsinny is the most-imported wrasse species, and on average about 265,000 individuals have been imported annually from Sweden in the last couple of years (see Figures 1.4.4.2-2 and 1.4.4.2-3). Most individuals are, however, imported after the main spawning season has ended in Norway. However, goldsinny spawns in open water and do not need to escape in order to spawn. It has also been documented that goldsinny wrasses spawn in the salmon cages, which increases the likelihood of imported individuals contributing to the local population. Goldsinny is also the smallest of the three wrasse species and is therefore expected to have a higher escape rate that the two others.

The project group assessed that that the likelihood of negative effects on biodiversity in Norway, in terms of genetic changes in local populations (although presumably smaller changes than for the other two species), as a result of import of *C. rupestris* as being likely, with high confidence.

#### *5.1.1.4 Lumpfish (C. lumpus)*

As lumpfish only function efficiently as cleaner fish when they are small, all lumpfish used in aquaculture today are farmed. There is currently no import of juvenile lumpfish (although this might become relevant in the future), but adult lumpfish are imported for use in breeding, and we will consider these first-generation bred imports as "imported", as they are of foreign descent. Compared with wild-caught wrasses, farmed lumpfish can more easily be delivered at a uniform size to the aquaculture facilities. This may, in turn, reduce the escape of below-average-sized fish, as stocking can be more precisely regulated according to mesh size. Moreover, in contrast to wrasses, juvenile lumpfish grow relatively fast, and changes in mesh size as the salmon grows may therefore not necessarily result in increased escapes. Also, escaped lumpfish would need to survive more than two seasons in order to reach sexual maturity. Both these facts reduce the likelihood of genetic changes occurring in the local populations due to the use of lumpfish as cleaner fish.

The project group assessed that the likelihood of negative effects on biodiversity in Norway, in terms of genetic changes in local populations, as result of the import of *C. lumpus* as unlikely, with low confidence.

### 5.1.2 Likelihood of spread of species beyond their natural ranges

The three wrasse species considered here are naturally distributed all along the Norwegian coast, except in Finnmark, Troms, and, to some degree, Nordland counties (see 1.5.1.1, 1.5.2.1 and 1.5.3.1). Wrasses are not very efficient lice eaters in colder water, and are thus generally not used in aquaculture as far north as their northernmost natural distribution (see 1.7.6-1).

#### *5.1.2.1 Corkwing wrasse (S. melops)*

Corkwing wrasses are used in aquaculture relatively close to their northernmost natural distribution. The project group therefore assessed that that the likelihood of import of *S. melops* resulting in spreading of this species beyond its natural range as moderately likely, with high confidence.

#### *5.1.2.2 Ballan wrasse (L. bergylta)*

Ballan wrasses are currently not used in the close vicinity of their northernmost natural distribution. The project group therefore assessed that the likelihood of import of *L. bergylta* resulting in spreading of this species beyond its natural range as unlikely, with medium confidence.

#### *5.1.2.3 Goldsinny (C. rupestris)*

Goldsinny wrasses are only used as a cleaner fish well within their area of natural distribution. The project group therefore assessed that the likelihood of import of *C. rupestris* resulting in spreading of this species beyond its natural range as very unlikely, with high confidence.

#### *5.1.2.4 Lumpfish (C. lumpus)*

Lumpfish is naturally distributed all along the Norwegian coast, and the project group therefore assessed that the likelihood of import of *C. lumpus* resulting in spreading of this species beyond its natural range as very unlikely, with very high confidence.

### 5.1.3 Likelihood of transfer of novel infectious agents to Norway

Fish farming provides the possibility for routine screening for selected pathogens as a preventive measure to avoid transmission, which is less feasible to conduct on batches of wild-caught fish. Today, most farmed lumpfish and ballan wrasse are also vaccinated against a few of the most well-known bacterial cleaner fish pathogens, although much work remains to be done in terms of achieving adequate levels of protection. Moreover, vaccines against a pathogen may not always provide cross-protection against the entire strain-spectrum and, in addition, will not necessarily represent a guarantee against subclinical carrier status. Subclinical infections may become activated at some later stage and spread to unvaccinated, wild fish.

#### *5.1.3.1 All relevant wrasses*

The project group assessed that the likelihood of negative consequences to Norwegian biodiversity from introduction and spread of the selected infectious agents would be:

- Likely, with medium confidence for *Microcotyle donavini.* This parasite may already occur in Norway, but, if so, possibly not be present along the whole coast. Introduced strains of this parasites may be more virulent in Norway than in their area of origin, and, as a result of the direct lifecycle, could become numerous on individual fish.
- Moderately likely, with low confidence for *Macvicaria alacris.* Trematodes in the digestive tract of fish are usually considered harmless, but may become more harmful when introduced to new areas, especially to the intermediate invertebrate hosts.
- Moderately likely, with low confidence for *Gaevskayatrema perezi.* Trematodes in the digestive tract of fish are usually considered harmless, but may become more harmful when introduced to new areas, especially to the intermediate invertebrate hosts.
- Moderately likely, with medium confidence for NNV. The virus is widespread in wrasses in Norway, and therefore the transfer of cleaner fish from one area to another increases the probability of spread of the virus. The infection may have consequences for its host animal, i.e., cleaner fish.
- Moderately likely, with low confidence for VHSV. The virus is widespread among marine fish, can infect a large number of different fish species, and has large pathogenic potential.
- Unlikely, with low confidence for SAV. SAV has not been found in cleaner-fish species in Norway to date, but has been identified once in a wrasse in an aquaculture pen in Ireland (during a PD-outbreak).
- Unlikely, with low confidence for *Aeromonas salmonicidia*. *A. salmonicida* represents a significant pathogen of wrasses used as cleaner fish, both in Norway and the British Isles, and characterization of recovered isolates has revealed that identical strains dominate in both places. However, the possible existence of yet-undescribed strains that are able to infect wrasse species in areas relevant for import cannot be disregarded.

Healthy carriers of bacterial and viral infectious agents are, to some extent, expected to succumb to infection due to stress during transport and stocking, and display symptoms. This should reduce the likelihood of infected fish being used in aquaculture.

#### *5.1.3.2 Lumpfish (C. lumpus)*

The project group assessed that the likelihood of negative consequences to Norwegian biodiversity from introduction and spread of the selected infectious agents would be:

- Very unlikely, with high confidence for VHSV as all lumpfish used in aquaculture is farmed. The virus is widespread among marine fish, can infect a large number of different fish species, and has large pathogenic potential.

- Moderately likely, with medium confidence for lumpfish ranavirus. Ranavirus has been found on lumpfish in aquaculture on Iceland. Ranaviruses are common infections in many poikilothermic animals, including fish, and some ranaviruses are particularly pathogenic to fish.
- Very unlikely, with low confidence for *Aeromonas salmonicida. A. salmonicida* represents a significant pathogen of lumpfish used as cleaner fish both in Norway and the British Isles, and characterization of recovered isolates have revealed that identical strains dominate in both places. However, the possible existence of yet undescribed strains that are able to infect lumpfish in areas relevant for import cannot be disregarded. *A. salmonicida* is one of the agents against which most farmed lumpfish are currently routinely vaccinated.
- Moderately likely, with medium confidence for *Pasteurella skyensis* / *Pasteurella* sp. Relatively little is known about the *Pasteurella* sp. occurring in lumpfish in the British Isles, which may or may not be identical to the two distinct strains typically observed in Norwegian lumpfish and salmon. No vaccines exist against this pathogen.
- Unlikely, with medium confidence for *Piscirickettsia salmonis.* Only a single report exists documenting *P. salmonis* in Irish lumpfish.

### 5.1.4 Likelihood of negative impact on biodiversity from import of cleaner fish in general

#### *5.1.4.1 Introduction of other alien organisms through bycatch*

Imported wrasses are sold individually, and counted by hand, so although it is very likely that other species, specifically the round goby (*N. melanostomus*), would be caught as bycatch, it is likely to be identified in screening and removed before it is transported to Norway. However, this practice may change, and the project group therefore assessed that it is unlikely, with low confidence, that import of cleaner fish will result in spread of the round goby and other fish species to Norwegian waters.

#### *5.1.4.2 Introduction of other alien organisms in transport water*

Unless preventive measures are taken, the project group assessed that it is likely, with low confidence, that alien organisms (e.g. the Pacific oyster) will be introduced to Norway (and have negative effects on biodiversity), via transport water used to hold the imported cleaner fish.

## 5.2 Likelihood of negative consequences in a 50-year perspective

The likelihood of negative genetic consequences in a long-term perspective relies on the extent of import, but also on the status of the local population. The likelihood will increase with escapes of imported fish over consecutive generations over the next 50 years.

However, aquaculture of lumpfish and ballan wrasse is developing, and it is uncertain whether the demand for imported wild-caught specimens will persist over the next decades.

The expert group assessed the likelihood of negative consequences from the release of imported cleaner fish to be moderate, with low confidence.

In general, an increase in average water temperature, as expected in scenarios from the IPCC (see section 3.3), mean that new species (e.g. infectious agents) imported from warmer sea areas can become more likely to establish in Norwegian waters.

# 6 Risk characterization

## 6.1 Risk of negative impacts related to import of specific cleaner-fish species to Norway

The overall risk of negative impact is determined both by the potential consequence of the different hazards and the likelihood of these consequences occurring. Likewise, the confidence in the overall risk denotes the combined confidence of the potential consequence and the likelihood.

### 6.1.1 Risk of genetic change of local populations

#### *6.1.1.1 Corkwing wrasse (S. melops)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of genetic changes in indigenous populations, following import of *S. melops* for use as cleaner fish in aquaculture, as moderate (bordering high), with medium to high confidence (see 4.1.1.1 and 5.1.1.1).

#### *6.1.1.2 Ballan wrasse (L. bergylta)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of genetic changes in indigenous populations, following import of *L. bergylta* for use as cleaner fish in aquaculture, as moderate, with low to medium confidence (see 4.1.1.2 and 5.1.1.2).

#### *6.1.1.3 Goldsinny (C. rupestris)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of genetic changes in indigenous populations, following import of *C. rupestris* for use as cleaner fish in aquaculture, as moderate (bordering high), with medium confidence (see 4.1.1.3 and 5.1.1.3).

#### *6.1.1.4 Lumpfish (C. lumpus)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of genetic changes in indigenous populations, following import of *C. lumpus* for use as cleaner fish in aquaculture, as moderate (bordering low), with low to medium confidence (see 4.1.1.4 and 5.1.1.4).

### 6.1.2 Risk concerning spread of species beyond their natural ranges

#### *6.1.2.1 Corkwing wrasse (S. melops)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of *S. melops* spreading beyond its natural range following its import for use as cleaner fish in aquaculture, as moderate (bordering low), with medium confidence (see 4.1.2.1 and 5.1.2.1).

#### *6.1.2.2 Ballan wrasse (L. bergylta)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of *L. bergylta* spreading beyond its natural range following its import for use as cleaner fish in aquaculture, as low (bordering moderate), with low to medium confidence (see 4.1.2.2 and 5.1.2.2).

#### *6.1.2.3 Goldsinny (C. rupestris)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of *C. rupestris* spreading beyond its natural range following its import for use as cleaner fish in aquaculture, as low, with medium confidence (see 4.1.2.3 and 5.1.2.3).

#### *6.1.2.4 Lumpfish (C. lumpus)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of *C. lumpus* spreading beyond its natural range following its import for use as cleaner fish in aquaculture, as low, with medium to high confidence (see 4.1.2.3 and 5.1.2.3).

### 6.1.3 Risk associated with transfer of novel infectious agents to Norway

As the relevant wrasse species have similar distribution ranges and are subject to the same infection pressures in the same areas, there are no obvious differences in the risks that they may pose in terms of transferring infectious agents. There is, however, a theoretical possibility of differences between the risks posed by wild-caught wrasses and farmed wrasses, but the project group has not assessed this to be the case, as vaccination is not mandatory).

#### *6.1.3.1 All relevant wrasses (S. melops, L. bergylta and C. rupestris)*

The project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of transfer of novel infectious agents following the import of wild caught wrasses, to be:

- Moderate (bordering high) regarding the gill parasite *Microcotyle donavini* and VHSV. Both assessments have medium confidence.
- Moderate (bordering low) regarding the salmon-affecting bacteria *Aeromonas salmonicida, with* low confidence.
- Low, with medium-to-low confidence, for the trematodes *Macvicaria alacris* and *Gaevskayatrema perezi,* and also for SAV and NNV.

#### *6.1.3.2 Lumpfish (C. lumpus)*

All lumpfish used in aquaculture in Norway are farmed, and the project group assessed that the risk of negative impacts on biodiversity in Norway, in terms of the transfer of novel infectious agents, following import of lumpfish to be:

- Moderate, with medium confidence, for VHSV.
- Moderate (bordering low), with medium-to-low confidence, for lumpfish ranavirus and the salmon-infecting *Pasteurella* sp. (i.e., *P. skyensis*).
- Low, with medium-to-low confidence, for the salmon-infecting bacteria *Aeromonas salmonicida* and *Piscirickettsia salmonis.*

### 6.1.4 Risk of negative impact on biodiversity from import of cleaner fish in general

#### *6.1.4.1 Introduction of other alien organisms through bycatch*

Alien organisms have the potential to cause massive damage to biodiversity in Norway. The project group assessed that although such organisms are unlikely to be introduced through bycatch, the consequences could be major, and therefore the overall risk associated with introduction of alien species through bycatch is moderate, with medium confidence.

#### *6.1.4.2 Introduction of other alien organisms in transport water*

Although it is likely that alien organisms will be introduced to Norway via transport water used for import of cleaner fish, they are assessed to pose a lesser threat to biodiversity than species introduced through bycatch. Therefore, the risk overall to biodiversity in Norway posed by transport water is assessed to be moderate, with low confidence.

## 6.2 Risk of negative consequences in a 50-year perspective

Cleaner fish that has been translocated within Norway has caused genetic change in local populations. Such transfer of genes can also occur from imported cleaner fish. The extent of import in future decades is, however, uncertain as the aquaculture of cleaner fish is developing. The expert group assessed that the risk of genetic impact caused by imported cleaner fish in a 50-year perspective to be moderate, with low confidence.

# 7 Risk-reduction measures

This report deals with potential risks associated with the import of cleaner fish. Here, we propose measures that could be implemented to reduce the risk.

**1) Only import fish outside the spawning season**

Importing fishes that have ended their spawning season would considerably reduce the likelihood of mating with the native population. This would minimize genetic changes to local populations due to mating with imported fish.

**2) Quarantine**

The panel assessed that a three-week quarantine period would be sufficient to reduce the likelihood of introducing pathogens.

**3) Vaccination**

Farmed fish, in particular, but also wild-caught fish, can be vaccinated against some diseases. This would significantly reduce the likelihood of introducing some of the most common pathogens.

**4) Health control and diagnostics**

Farmed fish and wild-caught fish held in holding pens could be inspected and tested for various pathogens to a larger extent than is currently customary. Implementing such controls would reduce the likelihood of introducing many of the pathogens to Norway.

**5) UV-treatment of transport water**

Water used to transport cleaner fish represents an important pathway of entry for many pathogens. By sterilizing the water (*e.g.* by UVC) after the fish have been removed, prior to water disposal, would also reduce the likelihood of introducing pathogens. However, larger organisms will not necessarily be killed by this procedure. Routinely testing the transport water for alien organisms is one way to identify and reduce the potential impact of this hazard.

**6) Restricted use in aquaculture of rainbow trout**

The pathogenic virus VHSV can replicate and multiply in rainbow trout, but not in Atlantic salmon. Restricting the use of wrasses in rainbow-trout facilities would thereby reduce the likelihood of this virus spreading.

**7) Short distances**

The genetic differences among populations of all the wrasse species discussed here increase with distance. Sourcing fishes for import from as close to the facility as possible would thus help to reduce the likelihood of genetic change in native populations. However, species specific patterns should be considered.

### 8) Land-based salmon farms

With land-based salmon farms the need for cleaner fish would cease to exist.

# 8 Uncertainties

## 8.1 Uncertainty regarding the number of fish caught, produced, and used

Our primary source of knowledge regarding the catch, production, and use of cleaner fish for Norwegian aquaculture has been provided by the Norwegian Directorate of Fisheries. However, the data indicate that the number of wrasses landed is significantly higher than the numbers reported as being deployed as cleaner fish. For example, 27.8 million wrasses were sourced from wild populations in 2017, but not more than 22.9 million wrasses were reported as being deployed as cleaner fish. Wild-caught wrasses are not used for food, so the numbers landed are exclusively sold as cleaner fish. Furthermore, there is a high number of wrasses of unspecified species in the aquaculture statistics (3.5 million in 2017). Some of these may be rock cook, but only 0.6 million individuals of this species were landed in 2017. Mortality in the transport phase between fisheries and fish farms could also contribute to the discrepancy; should this be the case, a very high number of fish die during transport. A better framework for tracking wild-sourced cleaner fish from sea to fish farm is certainly warranted.

## 8.2 Uncertainties relating to genetic structure data

The report describes the general biology, distribution, and current state of knowledge regarding the genetic structure for the relevant cleaner-fish species. However, although there are a few recent publications, reports describing the genetic population structuring in these species is generally limited. More research is clearly needed on this topic, especially studies designed to investigate fine-scale genetic structuring, local adaptation, and population connectivity. Without such knowledge, it is difficult to fully assess the consequences from translocating cleaner fish, as the differences in genetic composition within the source and recipient populations have a major impact on the outcome of such translocations in terms of genetic change. Thus, it is important that the genetic structures in both potential source populations, as well as in local recipient populations, in all cleaner-fish species that potentially could be translocated are investigated. As large genetic differences have been detected in both corkwing and ballan wrasses within Norway, translocation within Norway can also have an impact and increase the likelihood of genetic changes in local populations. Genetic studies should be accompanied by life-history data, such as growth, age, and size at maturity, longevity, and fecundity, as these traits strongly influence fitness and may therefore affect the probability of genetic change, and thus the probability of effects on the viability and adaptability of local populations following translocation.

Recent publications indicate clear evidence for ongoing genetic hybridization between translocated and native corkwing wrasses in Trøndelag, and strong indications that this is also the case for goldsinny wrasse (Faust et al. 2018; Jansson et al. 2017). These are proof-of-concept studies, but the magnitude and spatial pattern for hybridization should be further assessed, in addition to investigations of the fitness of escapees and hybrids relative to native wrasse. Furthermore, research may reveal significant genetic differences in the other relevant species or in other areas, and such information should, ideally, be taken into consideration.

All cleaner-fish species considered in this report are native to Norwegian waters, but may be introduced north of their current distribution range, except for lumpfish that is found throughout Norwegian waters. When a species establishes in a new environment, natural control mechanisms on abundance may become imbalanced. In addition, competition for food, predation on native species, and introduction of diseases may result in loss of biodiversity. Hence, it is difficult to assess without further research how translocation beyond the natural range will affect the ecosystem. For wrasses, there is no documentation (lack of research) indicating displacement or threat to other species occupying its niche, due to northerly spread following their use in aquaculture, and wrasses are not known to have a As lumpfish occur naturally along the Norwegian coast, spread to new areas following their use in aquaculture is not an issue, but potentially negative effects could be related to genetic changes in local populations due to introduction of genetically different individuals.

## 8.3 Uncertainties relating to novel infectious agents

In most cases, it is not known whether the same infectious agents isolated from cleaner fish in Norway or abroad (e.g. *Pasteurella* sp.) have a similar pathogenic potential. Such differences may be host dependent (i.e., geographically separated populations of the same fish species may vary in terms of susceptibility to infection and disease development). Moreover, limited information exists concerning the infection status of wild cleaner-fish populations. For pathogens naturally present in wild host populations at a low prevalence and/or covert infections large numbers of samples and/or highly sensitive tools are needed in order to estimate their prevalence with adequate certainty.

Most studies of parasites in cleaner fish have focused on metazoans. Several unicellular parasites are likely overlooked and, because most unicellular parasites have a direct lifecycle, they can become numerous and affect the fish health, particularly if the immune system of the fish is weak.

Although a range of well-described fish pathogens can be readily identified from infected cleaner fish, undescribed agents are intrinsically harder to detect. This is particularly true for viruses, the positive diagnosis of which commonly relies upon using molecular tools targeting specific (pre-known) segments of the agent’s genome. Traditional bacteriology may also fall short in the face of novel agents with distinctive growth requirements. Nevertheless, continuous improvements in high-throughput DNA/RNA sequencing have enabled the detection of several novel viral agents from fish in recent years, such as the CLuV (Skoge et al. 2018) from lumpfish. Although such approaches remain generally too expensive and time consuming for use in routine diagnostics and screening in veterinary medicine, they are expected to constitute important tools for such purposes in the years to come.

Notably, some established fish pathogens indigenous today in areas with higher water temperatures (e.g. *Lactococcus garviae* and *Photobacterium damselae* subsp. *piscicida*) are not yet considered to be important in the areas designated here as relevant for cleaner-fish import. However, this situation may change, depending on the future increases in ocean temperatures globally.

# 9 Conclusions (with answers to the terms of reference)

## 9.1 Areas relevant for import of cleaner fish

The wrasse species discussed in this report have similar distributions (1.5.1.1, 1.5.2.1 and 1.5.3.1), and thus also similar potential areas where export can be relevant. The most relevant areas for export of wrasses to Norway are the west coast of Sweden and Denmark. Import of wrasses from UK is also relevant. However, UK also has substantial salmonid aquaculture, and thus also a need for cleaner fish, so export might not be as likely.

Lumpfish are widely distributed (1.5.4.1), but all lumpfish used in aquaculture are farmed, so import would be limited to adult specimens used for breeding. As far as the project group can assess, there is little or no demand for import of additional breeding stock. One potential exception is import of adult fish from the Baltic Sea, where the local population has a slower growth rate that is preferable for their use as cleaner fish (1.5.4.2).

## 9.2 Summarized risk of negative impact related to genetic changes in local populations of cleaner fish

The risk of negative impacts related to genetic changes in local populations of cleaner fish is shown for each of the species in Figure 9.2-1. The risk is moderate for all four species, but both the overall likelihood and the severity of the potential impact varies among species. The project group assessed that the summarized risk borders being high for both *S. melops* and *C. rupestris* due to the strong genetic differences between different populations of *S. melops*, (see 1.5.1.2, 1.6.6, 3.2.1, 4.1.1.1, and 6.1.1.1.) and the potential for genetic recombination due to pelagic eggs and open-water spawning for *C. rupestris* (see 1.5.3.2, 1.6.6, 3.2.1, 4.1.1.3, and 6.1.1.3). The confidence in the individual assessments ranges from low to high (see 6.1.1), but over all the project group has medium confidence in these assessments (i.e. “Some published information exists on the topic, but expert judgements are still used” (Table 2.1.3)).

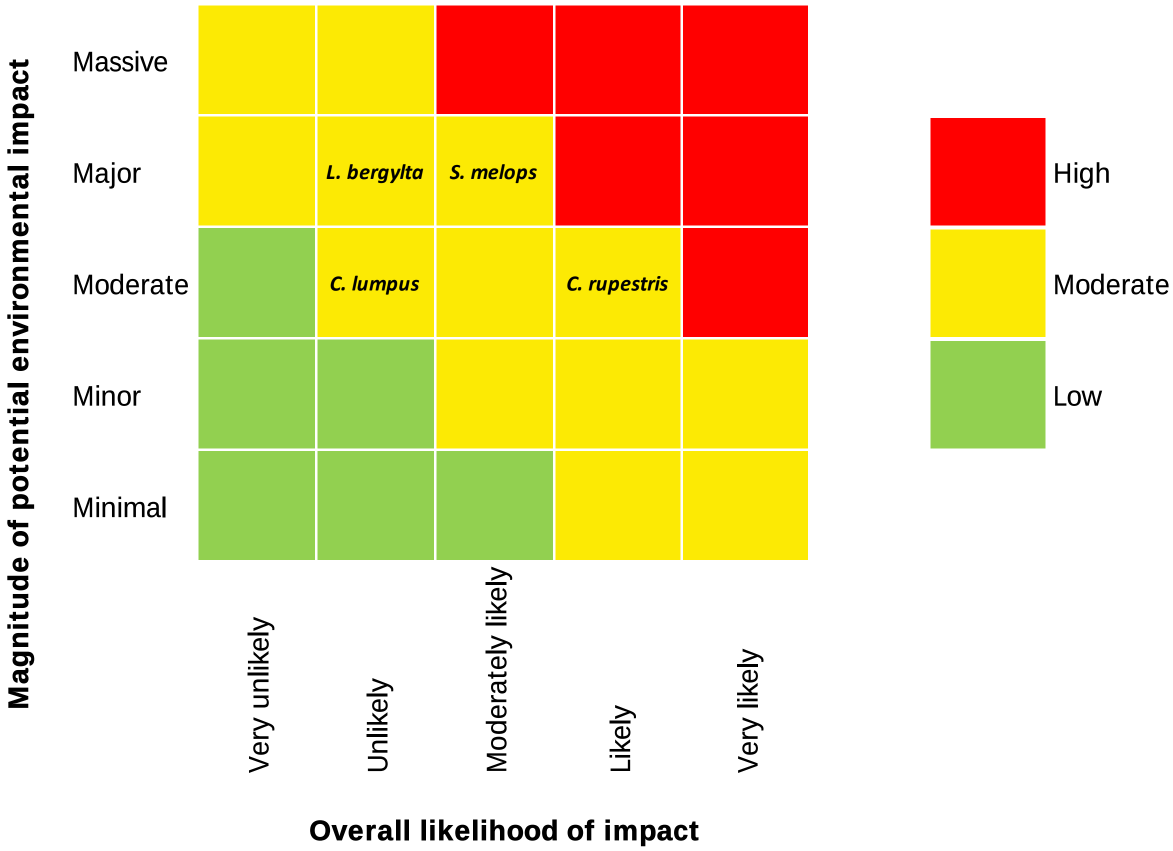


**Figure 9.2-1:** Summarized risk of negative impact related to genetic changes in local populations of cleaner fish

## 9.3 Summarized risk of negative impact related to spread of species beyond their natural ranges

The risk, in terms of negative impact related to spread of each of the species beyond their natural ranges, is shown in Figure 9.3-1. For three of the species, the risk is low. For *S. melops*, the risk is moderate, although the magnitude of the potential effect is minor (see 1.4.1, 1.5.1.1, 1.6.7, 1.7.1-1.7.6 and 4.1.2.1). ). The confidence in the individual assessments ranges from low to high (see 6.1.2), but over all the project group has medium confidence in these assessments (i.e. “Some published information exists on the topic, but expert judgements are still used” (Table 2.1.3)).

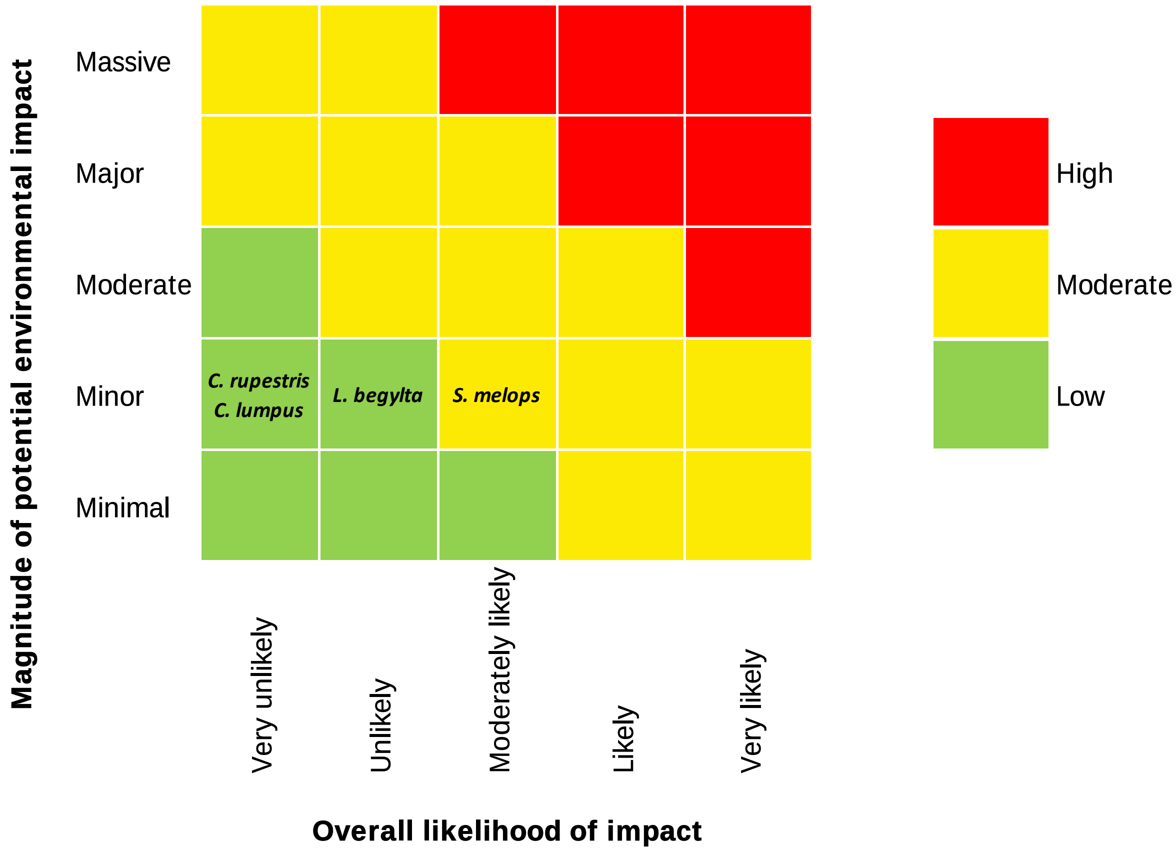


**Figure 9.3-1:** Summarized risk of negative impact related to spread beyond the species natural range

## 9.4 Summarized risk of negative impact related to introduction of infectious agents

A wide range of infectious agents can potentially be introduced with imported cleaner fish and cause negative impacts to biodiversity in Norway (1.6.1, 1.6.2 and 1.6.3). As the pathogens and the areas relevant for import are similar for the three wrasse species, it is assessed that there are no species-specific pathogens to consider (1.7.7 and 1.7.8). Of the seven pathogens considered most relevant by the project group, and potentially associated with import of wrasses (3.2.3.1), three pose a moderate risk, and four are associated with a low risk (Figure 9.4-1). The risk is moderate and near high for VHSV and *M. donovini*, and surveillance of these would be recommended. Over all, the project group has low to medium confidence in these assessments (see 6.1.3.1), as there is limited availability of publications on the hazards of these pathogens in Norway. Some published information exists, but expert judgements are still used (Table 2.1.3)).

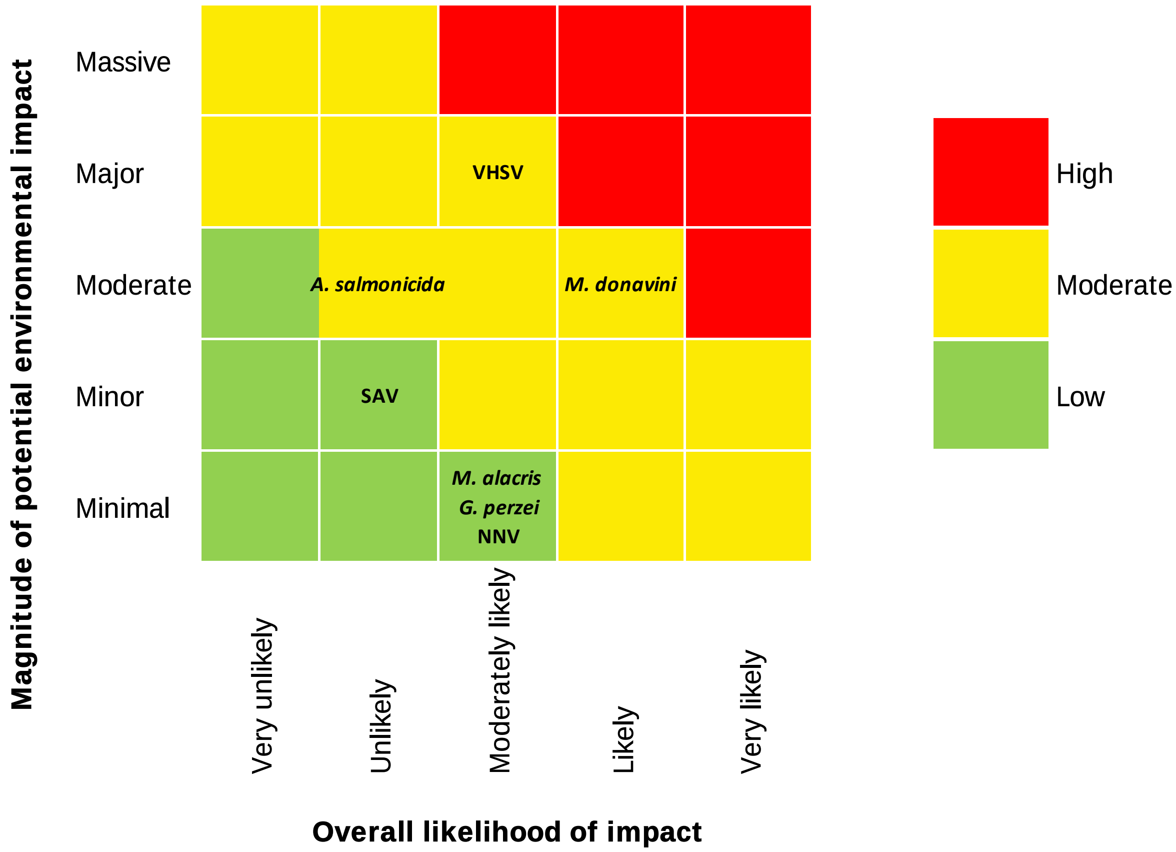


**Figure 9.4-1:** Summarized risk of negative impacts related to spread of infectious agents associated with importing wrasses

The overall risk associated with infectious agents that are relevant to consider regarding import of lumpfish is shown in Figure 9.4-2. All agents have a low risk, or moderate risk that is close to low, due to the low probability of these agents having any environmental impact through this pathway (5.1.3.2), or due to the minimal severity of any potential impact (4.1.3.2). Over all, the project group has low to medium confidence in these assessments (see 6.1.3.2), as there is limited availability of publications on the hazards of these pathogens in Norway. Some published information exists, but expert judgements are still used (Table 2.1.3)).

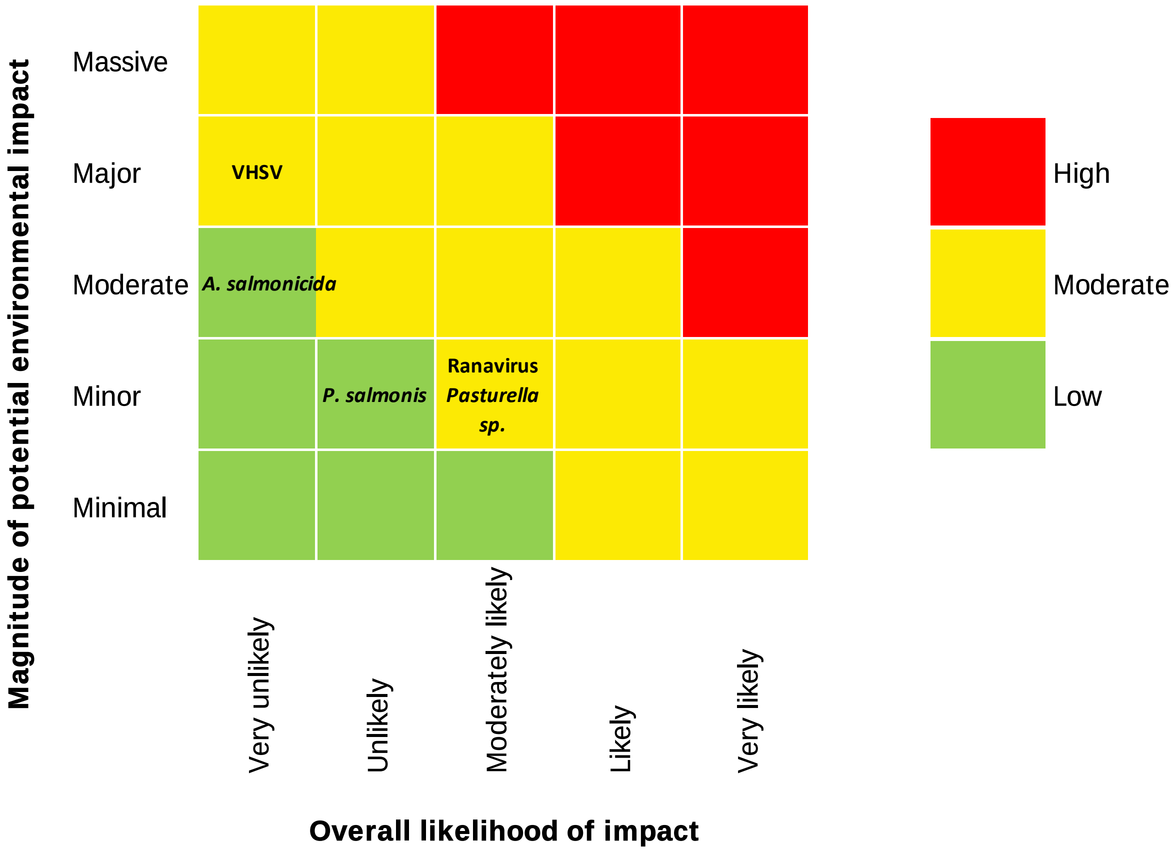


**Figure 9.4-2:** Summarized risk of negative impact related to spread of infectious agents associated with importing lumpfish

## 9.5 Summarized risk of negative impact related to other ecological hazards

The overall risks posed to biodiversity in Norway associated with introduction of alien organisms either as bycatch (1.6.8.1 and 3.2.4.1) or in the transport water (1.6.8.2 and 3.2.4.2) are assessed as being moderate (Figure 9.5-1). These assessments are based on the available, but limited information on these specific topics (e.g. species and their specific impact) in Norwegian waters, and expert opinions are therefor used extensively, and the confidence is low to medium (Table 2.1.3).

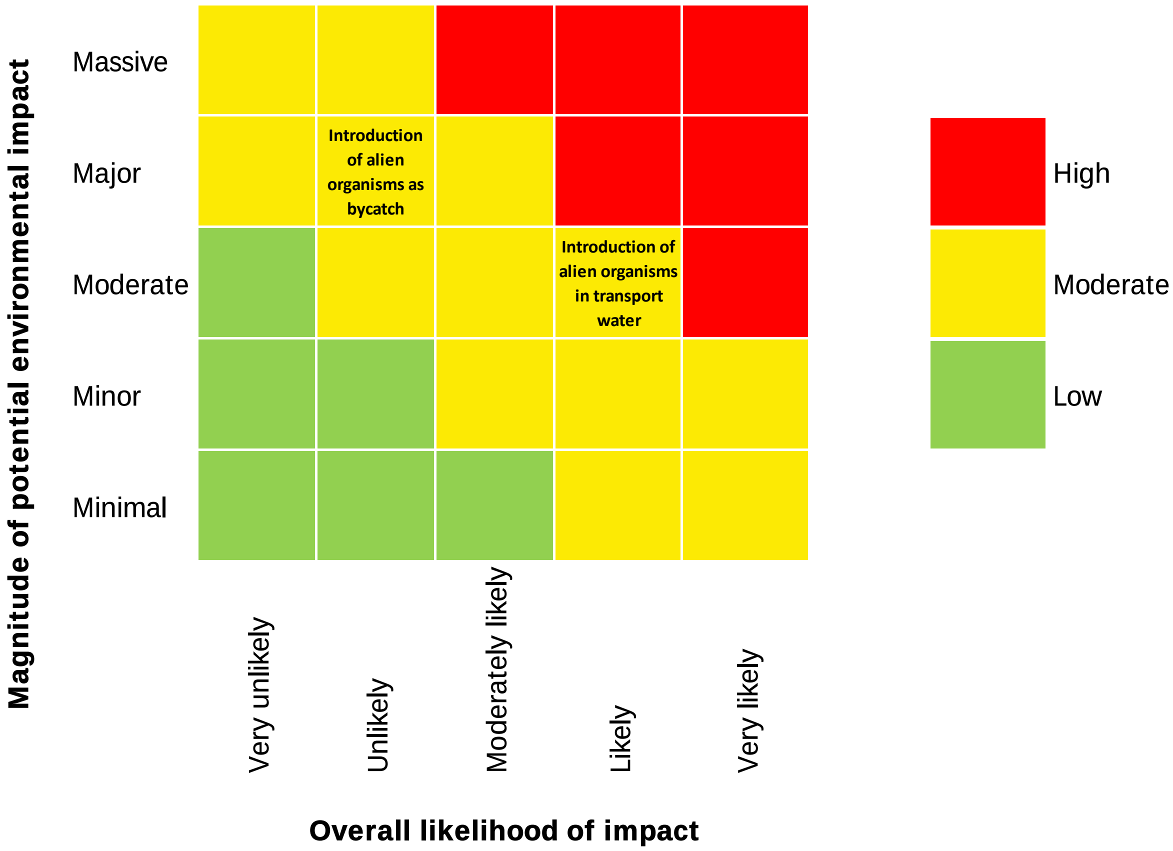


**Figure 9.5-1:** Summarized risk of negative impacts related to introduction of alien organisms

## 9.6 Summarized risk of negative impact in a 50-year perspective

The negative risk of negative impact in a 50-year perspective is relevant only for genetic changes and spread of species beyond their natural ranges. As the uncertainties regarding future import of cleaner fish and climate change are high, the cleaner-fish species have not been assessed individually. The risk of negative impacts from genetic change has been assessed as moderate, but the likelihood is low. Although the risk of negative impacts from the four cleaner-fish species described in this report has been assessed as generally low, other, non-native species could potentially be imported as cleaner fish and could spread when the sea temperature rises. However, this would need to be assessed separately when and if such information becomes available. Over all, the 50-year assessment has low confidence, as "Available information on the topic is limited, and mostly expert judgements are used" (Table 2.1.3)..

## 9.7 Information needed for qualified judgement calls

This report specifically covers the risks associated with the import of four species of cleaner fish, but many of the aspects and risks will also apply to other species. In order to make a qualified decision whether to import a new species or whether populations not covered in this report can pose a threat to biodiversity in Norway, the following information should be in place.

### 9.7.1 Information on genetic structure of local populations

If the species is indigenous to Norway, the genetic differences between the source population and the potential sink-population should be known. The difference can be calculated through different genetic screening arrays.

### 9.7.2 Information on the natural range and ecology of the species

For species not indigenous to Norway, special caution should be exercised. At the very least, a full-scale mapping of the biology, in terms of distribution, preferred temperature range, spawning behaviour, life history, longevity, feeding ecology of the proposed species is needed in order to evaluate whether it might represent a threat to biodiversity in Norway.

### 9.7.3 Information on important pathogens

The source population should be screened for, at the very least, the pathogens that are assessed in this report as posing a medium risk to biodiversity in Norway (see 9.4). Additional information on potentially foreign/novel pathogens is also needed.

### 9.7.4 Other important factors / information

In order to ensure a sustainable harvest of the source population, factors like the size of, and recruitment to, the population should be known in order to ensure that the likelihood of a negative impact is minimized. In addition, investigations are needed to find whether potentially invasive species exist in the source area, and if these can be transported either as bycatch or in the transport water with the imported species.

# 10 Data gaps

To decrease the uncertainty regarding the current practice of translocating and using cleaner fish, the extent and causes of escapes of each species should be investigated. Currently, there is virtually no information on escape rates, or where and when they occur. For example, if the primary cause of escape is a mismatch between mesh size in the salmon pens and the size of the cleaner fish, there is a considerable potential for reducing the likelihood of escape by reducing mesh size or increasing the minimum size of cleaner fish. Therefore, studies investigating spatial and temporal variations in condition factors, body shape, and escape potential through different mesh sizes are strongly encouraged.

Furthermore, in order to better understand the ecological impacts of escaped cleaner fish, the niche of wrasse and lumpfish in source- and recipient populations should be further investigated, such as prey composition, competition with other species, and spawning periods. This should preferably be done in large scale experiments, including control areas.

Similarly, where escape and translocation have already occurred, ecology, fitness, and life-history traits of escapees, hybrids, and native fish should be studied to assess the impact on the viability and adaptability of local populations in both the short and long term.

In general, there is a lack of data on the occurrence of infectious pathogens in wrasses and lumpfish in the wild. For instance, lumpfish ranavirus is present in Iceland, Faroe Islands, Scotland and Ireland, however its status in Norway is unknown. Such lack of data adds to the uncertainty of the risk assessment of the infectious agents, and thus the potential effects on the biodiversity.

# 11 References

Adams SB, Frissell CA, Rieman BE (2000) Movements of nonnative brook trout in relation to stream channel slope. Transactions of the American Fisheries Society, 129, 623-638.

Agusti C, Bravo S, Contreras G, Bakke MJ, Helgesen KO, Winkler C, Silva MT, Mendoza J, Horsberg TE (2016) Sensitivity assessment of *Caligus rogercresseyi* to anti-louse chemicals in relation to treatment efficacy in Chilean salmonid farms. Aquaculture 458, 195–205.

Alarcón M, Gulla S, Røsæg MV, Rønneseth A, Wergeland H, Poppe TT, Colquhoun DJ (2016) Pasteurellosis in lumpsucker *Cyclopterus lumpus*, farmed in Norway. Journal of Fish Diseases, 39(4).

Allendorf FW, Lundquist LL (2003) Introduction: population biology, evolution, and control of invasive species. Conserv. Biol. 17, 24-30.

Almada F, Casas L, Francisco SM, Villegas-Ríos D, Saborido-Rey F, Irigoien X, Robalo JI (2016) On the absence of genetic differentiation between morphotypes of the Ballan wrasse *Labrus bergylta* ( Labridae ). Marine Biology 163.

Alvsvåg J (1993) Fødeval, vekst og energiallokering hos gras gylt (*Centrolabrus exoletus* L.) og grønngylt (*Symphodus melops* L.) (Pisces: Labridae) på vestkysten av Noreg, og diettoverlapping med O og I-gruppe torsk (*Gadus morhua* L.). Hovedfagsoppgave i fiskeribiologi, Universitetet I Bergen.

Andersson, E (2019) Test av selektiva redskap för det svenska fisket efter läppfisk, Aqua reports 2019:1. Sveriges lantbruksuniversitet, Institutionen för akvatiska resurser, Lysekil, 54p.

Askeland J (2002) Parasites of Ballan wrasse, *Labrus bergylta* (Labridae), a cleaner fish in salmon pens. Master thesis, University of Bergen.

Austin B, Austin DA (2012) Bacterial Fish Pathogens: Diseases of Farmed and Wild Fish; Fifth Edition.

Baillon L, Meerour E, Cabon J, Louboutin L, Quenault H, Touzain F, Bremont M (2017) A single amino acid change in the non-structural NV protein impacts the virulence phenotype of Viral hemorrhagic septicemia virus in trout. Journal of General Virology, 98(6), 1181-1184.

Berg PR, Jentoft S, Star B, Ring KH, Knutsen H, Lien S, Jakobsen KS, André C (2015) Adaptation to low salinity promotes genomic divergence in Atlantic cod (*Gadus morhua* L.). Genome Biollogy and Evolution; 7, 1644-1663.

Bergh Ø, Samuelsen OB (2007) Susceptibility of corkwing wrasse *Symphodus melops,* goldsinny wrasse *Ctenolabrus rupestis*, and Atlantic salmon *Salmo salar* smolt, to experimental challenge with *Vibrio tapetis* and *Vibrio splendidus* isolated from corkwing. Aquaculture International, 15(1), 11–18.

Biering E, Vaagnes Ø, Krossøy B, Gulla S, Colquhoun D (2016) Challenge models for atypical *Aeromonas salmonicida* and *Vibrio anguillarum* in farmed Ballan wrasse (*Labrus bergylta* ) and preliminary testing of a trial vaccine against atypical *Aeromonas salmonicida*. Journal of Fish Diseases, 39(10), 1257–1261.

Birkbeck TH, Laidler LA, Grant AN, Cox DI (2002) *Pasteurella skyensis* sp. nov., isolated from Atlantic salmon (*Salmo salar* L.). International Journal of Systematic and Evolutionary Microbiology, 52, 699–704.

Bjordal Å (1988) Cleaning symbiosis between wrasse (Labridae) and lice infested salmon (*Salmo salar*) in mariculture. International Council for the Exploration of the Sea, 1988/F:17.

Blacker RW (1983) Pelagic records of the lumpsucker, *Cyclopterus lumpus* L. Journal of Fish Biology 23, 405–417.

Bolstad GH, Hindar K, Robertsen G, Jonsson B, Saegrov H, Diserud OH, Karlsson S (2017) Gene flow from domesticated escapees alters the life history of wild Atlantic salmon. Nature Ecology & Evolution, 1, 124

Bornø G, Gulla S (2016) Helsesituasjonen hos rensefisk. In: Hjeltnes, B.; Walde, C., Bang Jensen, B., Haukas (eds). Fiskehelserapporten 2015 Veterinærinstituttet 2016:70-73.

Boyce D, Ang KP, Prickett R (2018) Cunner and Lumpfish as cleaner fish species in Canada. Cleaner fish biology and aquaculture applications. Treasurer JW (ed.). 5M Publications. Sheffield, 444-467

Bridle JR, Vines TH (2007) Limits to evolution at range margins: when and why does adaptation fail? Trends in Ecology and Evolution, 22, 140-147.

Brooker AJ, Skern-Mauritzen R, Bron, JE (2018) Production, mortality, and infectivity of planktonic larval sea lice, *Lepeophtheirus salmonis* (Krøyer, 1837): current knowledge and implications for epidemiological modelling. ICES Journal of Marine Science 75:1214–1234.

Cavin JM, Donahoe SL, Frasca Jr S, Innis CJ, Kinsel MJ, KurobeT, Weber III ES (2012) *Myxobolus albi* infection in cartilage of captive lumpfish (*Cyclopterus lumpus*). Journal of Veterinary Diagnostic Investigation, 24(3), 516-524.

Colorni A, Ravelo C, Romalde JL, Toranzo AE, Diamant A (2003) *Lactococcus garvieae* in wild Red Sea wrasse *Coris aygula* (Labridae). Diseases of Aquatic Organisms, 56(3), 275–278.

Colquhoun DJ, Aase IL, Wallace C, Baklien Å, Gravningen K (2004) First description of *Vibrio ordalii* from Chile. Bulletin of the European Association of Fish Pathologists, 24(4), 185–188.

Colquhoun D, Duodu S, Nilsen HK, Sviland C, Vågnes Ø (2012) Helsesituasjonen hos marin fisk 2011. In: Olsen A.B., Hellberg H (eds). Fiskehelserapporten 2011. Veterinærinstiuttet 2012:33-38.

Colquhoun D (2019) Andre bakterieinfeksjoner. In: Hjeltnes B., Bang Jensen B., Bornø G., Haukas A., Walde C., (eds). Fiskehelserapporten 2018. Veterinærinstituttet 2019:76.

Consuegra S, Pooley C, Powell A, Keay A, Galloway G, Cockerill D, Garcia de Leaniz C (2015) A traceability and genetic screening programme for sustainable breeding of lumpfish (*Cyclopterus lumpus*) for sea lice control in salmon farming. In: Proceedings of Aquaculture Europe 2015. Rotterdam, European Aquaculture Society, 167.

Costello MJ (1991) A review of the biology of wrasse (Labridae: Pisces) in Northern Europe. Progress in Underwater Science 16, 29–51.

Costello MJ, Deady S, Pike, Fives JM (1996) Parasites and diseases of wrasse being used as cleaner-fish on salmon farms in Ireland and Scotland, in Wrasse: biology and use in aquaculture, ed by MDJ Sayer, JW Treasurer and MJ Costello, Fishing News Books, Oxford, pp 211– 227

D'Arcy J, Mirimin L, FitzGerald R (2013) Phylogeographic structure of a protogynous hermaphrodite species, the Ballan wrasse *Labrus bergylta*, in Ireland, Scotland, and Norway, using mitochondrial DNA sequence data. ICES Journal of Marine Science 70, 685–693.

Darwall WRT, Costello MJ, Donelly R, Lysaght S (1992) Implications of life-history strategies for a new wrasse fishery. Journal of Fish Biology 41, 111–123.

Davenport J (1985) Synopsis of biological data on the lumpsucker, *Cyclopterus lumpus* (Linnaeus, 1758). FAO Fishery Synopsis. Vol. 147, p. 31.

Davie A, Papadopoulou A, Brooker AJ, Migaud H, Rey S, Gutierrez C (2018) Sustainable production and use of cleaner fish for the biological control of sea lice: recent advances and current challenges. Veterinary Record 183, 383–383.

Deady S, Fives JM (1995) Diet of Ballan wrasse, *Labrus bergylta*, and some comparisons with the diet of corkwing wrasse, *Crenilabrus melops*. Journal of the Marine Biological Association of the United Kingdom 75, 651–665.

Dipper FA, Bridges CR, Menz A (1977) Age, growth and feeding in the Ballan wrasse *Labrus bergylta* Ascanius 1767. Journal of Fish Biology, 105–120.

DN 12.12.2018. Rekordhøye lønnskostnader i lakseoppdrett. https://www.dn.no/havbruk/lakselus/laks/lakseoppdrett/rekordhoye-lonnskostnader-i-lakseoppdrett/2-1-497924.

Einer-jensen K, Ahrens P, Forsberg R, Lorenzen N (2004) Evolution of the fish rhabdovirus viral haemorrhagic septicaemia virus. Journal of General Virology, 85, 1167-1179.

Essbauer S, Ahne W (2001) Viruses of lower vertebrates. Journal of Veterinary Medicine Series B-Infectious Diseases and Veterinary Public Health, 48(6), 403-475.

Faust E, Halvorsen KT, Andersen P, Knutsen H, André C (2018) Cleaner fish escape salmon farms and hybridize with local wrasse populations. Royal Society Open Science.

Forsgren E, Florin AB (2018) Svartmunnet kutling – en invaderende fremmed fiskeart på vei mot Norge. NINA Rapport 1454. Norsk institutt for naturforskning.

Garcia-Mayoral E, Olsen M, Hedeholm R, Post S, Nielsen EE, Bekkevold D (2016) Genetic structure of West Greenland populations of lumpfish *Cyclopterus lumpus*. Journal of Fish Biology 89, 2625–2642.

Gibson DR, Sommerville C (1996) The potential for viral problems related to the use of wrasse in the farming of Atlantic salmon. In M. D. J. Sayer, J. W. Treasurer, & M. J. Costello (Eds.), Wrasse Biology and use in Aquaculture (pp. 240-246). Oxford: Blackwell.

Gibson DR, Smail DA, Sommerville C (1998) Infectious pancreatic necrosis virus: experimental infection of goldsinny wrasse, *Ctenolabrus rupestris* L. (Labridae). Journal of Fish Diseases, 21(6), 399-406.

Gonzalez L, Carvajal J (2003) Life cycle of *Caligus rogercresseyi*, (Copepoda: Caligidae) parasite of Chilean reared salmonids. Aquaculture 220:101-117

Gonzalez EB, Knutsen H, Jorde PE (2016) Habitat discontinuities separate genetically divergent populations of a rocky shore marine fish. PloS one 11, e0163052.

Graham DA, Fringuelli E, Rowley HM, Cockerill D, Cox DI, Turnbull T, Mc Loughlin MF (2012) Geographical distribution of salmonid alphavirus subtypes in marine farmed Atlantic salmon, *Salmo salar* L., in Scotland and Ireland. Journal of Fish Diseases, 35(10), 755-765.

Gudmundsdottir S, Vendramin N, Cuenca A, Sigurdardottir H, Kristmundsson A, Iburg TM, Olesen NJ (2019) Outbreak of viral haemorrhagic septicaemia (VHS) in lumpfish

(*Cyclopterus lumpus*) in Iceland caused by VHS virus genotype IV. Journal of Fish Diseases, 42(1), 47-62.

Gulla S, Sørum H, Vågnes Ø, Colquhoun DJ (2015) Phylogenetic analysis and serotyping of *Vibrio splendidus*-related bacteria isolated from salmon farm cleaner fish. Diseases of Aquatic Organisms, 117(2).

Gulla S, Lund V, Kristoffersen AB, Sørum H, Colquhoun D (2016) 'vapA (A-layer) typing differentiates *Aeromonas salmonicida* subspecies and identifies a number of previously undescribed subtypes', Journal of Fish Diseases, 39(3), pp. 329–342.

Gulla S, Rønneseth A, Sørum H, Vågnes Ø, Balboa S, Romalde J, Colquhoun D (2017) Vibrio tapetis from wrasse used for ectoparasite bio-control in salmon farming: phylogenetic analysis and serotyping. Diseases of Aquatic Organisms, 125(3), 189–197.

Gulla S, Bornø G (2018) Helsesituasjonen hos rensefisk. In: Hjeltnes B., Bang Jensen B., Bornø G., Haukas A., Walde C., (eds). Fiskehelserapporten 2017 Veterinærinstituttet 2018:97-101.

Halvorsen KT, Sørdalen TK, Vøllestad LA, Skiftesvik AB, Espeland SH, Olsen EM (2016b) Sex- and size-selective harvesting of corkwing wrasse (*Symphodus melops*)—a cleaner fish used in salmonid aquaculture. ICES Journal of Marine Science: Journal du Conseil.

Halvorsen KT, Sørdalen TK, Durif C (2016a) Male-biased sexual size dimorphism in the nest building corkwing wrasse (*Symphodus melops*): implications for a size regulated fishery. ICES Journal of Marine Science: Journal du Conseil.

Halvorsen KT, Larsen T, Sørdalen TK, Vøllestad LA, Knutsen H, Olsen EM (2017a) Impact of harvesting cleaner fish for salmonid aquaculture assessed from replicated coastal marine protected areas. Marine Biology Research 13, 359–369.

Halvorsen KT, Bjelland R, Jørgensen T, Skiftesvik AB (2017b) Forsøksfiske for selektiv fangst av berggylt. Fisken og Havet. Rapport fra Havforskningen.

Hammer MP, Adams M, Unmack PJ, Walker KF (2007) A rethink on Retropinna: conservation implications of new taxa and significant genetic sub-structure in Australian smelts (Pisces: Retropinnidae). Marine and Freshwater Research, 58, 327-341.

Hanssen-Bauer I, Førland EJ, Haddeland I, Hisda lH, Mayer S, Nesje A, Nilsen JEØ, Sandven S, Sandø AB, Sorteberg A, Ådlandsvik B (2015) Klima i Norge 2100: Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015, Norwegian Centre for Climate Services (NCCS), Oslo, Norway, 204 pp.

Harkestad LS, Karlsbakk E, Skår C, Einen ACB, Mortensen S (2010) Hvorfor dør leppefisken i merdene? Havforskningsrapporen 2010. Fisken og Havet, Særnummer 1-2010. 163 pp.

Harkestad LS (2011) Experimental infections of corkwing, *Symphodus melops*, with the *Vibrio tapetis* strains CECT 4600, LP2 and NRP45. Msc thesis, University of Bergen, Department of Biology: 136 pages.

Hilldén NO (1984) Behavioural ecology of the labrid fishes (Teleostei, Labridae) at Tjärnö on the Swedish west coast. University of Stockholm, Dept. of Zoology and Tjärnö Marine Biological Laboratory

Hjeltnes B, Bornø G, Jansen MD, Haukaas A, Walde C (2016) The Health Situation in Norwegian Aquaculture 2015, Norwegian Veterinary Institute, Oslo.

Hjeltnes B, Bornø G, Jansen MD, Haukaas A, Walde C (2017). The Health Situation in Norwegian Aquaculture 2016, Norwegian Veterinary Institute, Oslo.

Hjeltnes B, Bornø G, Jansen MD, Haukaas A, Walde C (2018) The Health Situation in Norwegian Aquaculture 2017, Norwegian Veterinary Institute, Oslo.

IPCC. (2013) Summary for Policymakers, in: T. F. Stocker, et al. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ito T, Kurita J, Mori K, Olesen NJ (2016) Virulence of viral haemorrhagic septicaemia virus (VHSV) genotype III in rainbow trout. Vet Res, 47.

Jansson E, Quintela M, Dahle G (2017) Genetic analysis of goldsinny wrasse reveals evolutionary insights into population connectivity and potential evidence of inadvertent translocation via aquaculture. ICES Journal of Marine Science.

Jelmert A, Gulliksen B, Oug E, Sundet J, Falkenhaug T (2018) *Crassostrea gigas*, vurdering av økologisk risiko. Fremmedartslista 2018. Artsdatabanken. Hentet (2019, 12. juni) fra https://artsdatabanken.no/Fab2018/N/1050

Jensen S, Samuelsen OB, Andersen K, Torkildsen L, Lambert C, Choquet G, Bergh O (2003) Characterization of strains of *Vibrio splendidus* and *V. tapetis* isolated from corkwing wrasse *Symphodus melops* suffering vibriosis. Diseases of Aquatic Organisms, 53(1), 25–31.

Johannesen Á, Arge R, Eliasen K (2018) Rearing, farm application and behaviour of lumpfish (*Cyclopterus lumpus*) in the Faroes. Pp. 429-443. In: Treasurer J. (Ed.) Cleaner fish biology and aquaculture applications. 5M Publishing Ltd. 519 pp.

Jónsdóttir ÓDB, Schregel J, Hagen SB, Tobiassen C, Aarnes SG, Imsland AK (2017) Population genetic structure of lumpfish along the Norwegian coast: aquaculture implications. Aquaculture International 1:1-12.

Jónsdóttir ÓDB, Imsland AK, Kennedy J (2018) Lumpfish biology, genetics, use of microsatellites and SNP for population genetics and parental assignment, seek for QTLs. Pp. 218-228. In: In: Treasurer J. (Ed.) Cleaner fish biology and aquaculture applications. 5M Publishing Ltd. 519 pp.

Jørgensen T, Bjelland R, Halvorsen K, Durif C, Shema S, Skiftesvik AB (2017) Seleksjon i leppefiskredskap. Fisken og Havet. Rapport fra Havforskningen.

Karbowski CM, Finstad B, Karbowski N, Hedger RD (2019) Sea lice in Iceland: assessing the status and current implications for aquaculture and wild salmonids. Aquacult Environ Interact 11:149-160

Karlsbaak E, Hodneland K and Nylund A, Health status of goldsinny wrasse, including a detailed examination of the parasite community at Flodevigen, southern Norway, in Wrasse: biology and use in aquaculture, ed by MDJ Sayer, JW Treasurer and MJ Costello, Fishing News Books, Oxford, pp 228– 239

Karlsbakk E, Alarcon M, Hansen H, Nylund A (2014) Sykdom og parasitter i vill og oppdrettet rognkjeks. Fisken og Havet, Særnummer 1-2014: 37-39.

Kawecki TJ, Ebert D (2004) Conceptual issues in local adaptation. Ecology Letters, 7, 1225-1241.

Kennedy J, Jonsson S, Kasper JM, Olafsson HG (2015) Movements of female lumpfish (*Cyclopterus lumpus*) around Iceland. ICES Journal of Marine Science 72, 880–889.

Knutsen H, Jorde PE, Gonzalez EB, Robalo J, Albretsen J, Almada V (2013) Climate change and genetic structure of leading edge and rear end populations in a northwards shifting marine fish species, the corkwing wrasse (*Symphodus melops*). PloS one 8, e67492.

Korsnes K, Karlsbakk E, Skar CK, Saelemyr L, Nylund A, Kvamme BO, Mortensen S (2017) High nervous necrosis virus (NNV) diversity in wild wrasse (Labridae) in Norway and Sweden. Diseases of Aquatic Organisms, 126(1), 43-50.

Kvenseth, AM (1998) Wrasse – do they transfer diseases to salmon? Caligus, 5 2-4

Laikre L, Schwartz MK, Waples RS, Ryman N, The GeM Working Group (2010) Compromising genetic diversity in the wild: unmonitored large-scale release of plants and animals. Trends in Ecology and Evolution, 25, 520-529.

Lande R (1976) Natural selection and random genetic drift in phenotypic evolution. Evolution, 30, 314-334.

Lie KK, Tørresen OK, Solbakken MH (2018) Loss of stomach, loss of appetite? Sequencing of the ballan wrasse (*Labrus bergylta*) genome and intestinal transcriptomic profiling illuminate the evolution of loss of stomach function in fish. BMC Genomics 19, 186.

Lorance P, Cook R, Herrera J, de Sola L, Florin A, Papacon- stantinou C (2015) *Cyclopterus lumpus*. The IUCN Red List of Threatened Species 2015: e.T18237406A45078284. [Cited 22 Oct 2016.] Available from URL: http://www.iucnredlist.org/ details/18237406/1

Lymbery AJ, Morine M, Kanani HG, Beatty SJ, Morgan DL (2014) Co-invaders: the effects of alien parasites on native hosts. International Journal for Parasitology: Parasites and Wildlife, 3(2), 171-177.

Lynch M (1991) The genetic interpretation of inbreeding depression and outbreeding depression. Evolution, 45(3), 622-629.

Marcogliese DJ (2005) Parasites of the superorganism: are they indicators of ecosystem health?. International journal for parasitology, 35(7), 705-716

Marcos-López M, Donald K, Stagg H, McCarthy U (2013) Clinical Vibrio anguillarum infection in lumpsucker Cyclopterus lumpus in Scotland. The Veterinary record. BMJ Publishing Group Limited, 173(13), p. 319.

Marcos-López M, Ruane NM, Scholz F, Bolton-Warberg M, Mitchell SO, Murphy O'Sullivan S, Rodger HD (2017) *Piscirickettsia salmonis* infection in cultured lumpfish (*Cyclopterus lumpus* L.). Journal of Fish Diseases.

Maroni K, Andersen P (1996) Distribution and abundance of wrasse in an area of northern Norway. In: Wrasse: Biology and use in Aquaculture. (eds M.D.J. Sayer, M.J. Costello and J.W. Treasurer). Oxford: Fishing News Books, pp 70–73.

Matejusova I, Noguera PA, Hall M, McBeath AJA, Urquhart K, Simons J, Bruno DW (2016) Susceptibility of goldsinny wrasse, *Ctenolabrus rupestris* L. (Labridae), to viral haemorrhagic septicaemia virus (VHSV) genotype III: Experimental challenge and pathology. Vet Microbiol, 186, 164-173.

McCleary S, Giltrap M, Henshilwood K, Ruane NM (2014) Detection of salmonid alphavirus RNA in Celtic and Irish Sea flatfish. Diseases of Aquatic Organisms, 109(1), 1-7.

Mo TA, Poppe TT (2018) Risiko ved bruk av rensefisk i fiskeoppdrett. Norsk Veterinærtidsskrift; 9(130), 90-92.

Mo TA, Poppe TT (2019) Hvorfor er det ingen som bryr seg om dyrevelferd hos rensefisk? Veterinærtidsskrift; 4(131), 235- 236.

Mortensen S, Skiftesvis AB, Karlsbakk E, Sandlund N (2018) Miljøpåvirkning knyttet til bruk av rensefisk i oppdrett av laksefisk. Kapittel 10 i Havforskningsinstituttets årsrapport 2018.

Munro ES, McIntosh RE, Weir SJ, Noguera PA, Sandilands JM, Matejusova I, Smith R (2015) A mortality event in wrasse species (Labridae) associated with the presence of viral haemorrhagic septicaemia virus. Journal of Fish Diseases, 38(4), 335-341.

Muncaster S, Norberg B, Andersson E (2013) Natural sex change in the temperate protogynous Ballan wrasse *Labrus bergylta*. Journal of Fish Biology 82, 1858–1870.

Nehring S (2011) NOBANIS – Invasive Alien Species Fact Sheet – *Crassostrea gigas*. From: Online Database of the European Network on Invasive Alien Species - NOBANIS www.nobanis.org

Nilsen A, Viljugrein H, Røsæg MV, Colquhoun D (2014) Rensefiskhelse - kartlegging av dødelighet og dødelighetsårsaker. Norwegian Veterinary Institute's Report Series 12-2014.

Nissling A, Kryvi H, Vallin L (1994) Variation in egg buoyancy of Baltic cod *Gadus morhua* and its implications for egg survival in prevailing conditions in the Baltic Sea. Marine Ecology Progress Series, 110, 67-74.

Olsen AB, Melby HP, Speilberg L, Evensen, Håstein T (1997) *Piscirickettsia salmonis* infection in Atlantic salmon *Salmo salar* in Norway - Epidemiological, pathological and microbiological findings. Diseases of Aquatic Organisms, 31(1), 35–48.

Olsen AB, Gulla S, Steinum T, Colquhoun DJ, Nilsen HK, Duchaud E (2017) Multilocus sequence analysis reveals extensive genetic variety within *Tenacibaculum* spp. associated with ulcers in sea-farmed fish in Norway. Veterinary Microbiology, 205.

Olsen EM, Halvorsen KT, Larsen T, Kuparinen A (2018) Potential for managing life history diversity in a commercially exploited intermediate predator, the goldsinny wrasse (*Ctenolabrus rupestris*). ICES Journal of Marine Science.

Pampoulie C, Skirnisdottir S, Olafsdottir G, Helyar SJ, Thorsteinsson V, Jonsson SP, Frechet A, Durif CMF, Sherman S, Lampart-Kaluzniacka M, Hedeholm R, Olafsson H, Danielsdottir AK, Kasper JM (2014) Genetic structure of the lumpfish *Cyclopterus lumpus* across the North Atlantic. ICES Journal of Marine Science 71, 2390–2397

Parin NV, Fedorov, VV, Sheiko BA (2002) An annotated catalogue of fish-like vertebrates and fishes of the seas of Russia and adjacent countries: Part 2. Order Scorpaeniformes. Journal of Ichthyology 42 (Suppl.1), S60–S135.

Poppe TT, Taksdal T, Skjelstad H, Svieland C, Vågnes Ø, Colquhoun DJ (2012) Nye arter – nye diagnostiske utfordringer. Norsk Veterinærtidsskrift, 124, 19–21.

Potts GW (1985) The nest structure of the corkwing wrasse, *Crenilabrus melops* (Labridae: Teleostei). Journal of the Marine Biological Association of the United Kingdom 65, 531–546.

Powell A, Pooley C, Scolamacchia M, Garcia de Leaniz C (2018) Review of lumpfish biology. In: Treasurer JW, ed. Cleaner fish biology and aquaculture applications. Sheffield: 5M Publishing Ltd, 98-121.

Prickett R (2016) A review of cleaner fish production in the UK. Bulletin Aquaculture Association of Canada. 2016-2, 53-58.

Quintela M, Danielsen EA, Lopez L (2016) Is the Ballan wrasse (*Labrus bergylta*) two species? Genetic analysis reveals within-species divergence associated with plain and spotted morphotype frequencies. Integrative Zoology 11, 162–172.

R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Reid HI, Griffen AA, Birkbeck TH (2004) Isolates of *Piscirickettsia salmonis* from Scotland and Ireland show evidence of clonal diversity. Applied and Environmental Microbiology, 70(7), 4393–4397.

Reiss H, Hoarau G, Dickey-Collas M, Wolff WJ (2009) Genetic population structure of marine fish: mismatch between biological and fisheries management units. Fish and Fisheries, 10, 361-395.

Richter-Boix A, Teplitsky C, Rogell B, Laurila A. (2010). Local selection modifies phenotypic divergence among *Rana temporaria* populations in the presence of gene flow. Molecular Ecology, 19, 716-731.

Riley A, Jeffery K, Cochrane-Dyet T, White P, Ellis J (2017) Northern European Wrasse – Summary of commercial use, fisheries and implications for management.

Robalo JI, Castilho R, Francisco SM (2012) Northern refugia and recent expansion in the North Sea: the case of the wrasse *Symphodus melops* (Linnaeus, 1758). Ecology and evolution 2, 153–64.

Rolbiecki, L., & Rokicki, J. (2008). Helminths of the lumpsucker (*Cyclopterus lumpus*) from the Gulf of Gdańsk and Vistula Lagoon (Poland). Oceanological and Hydrobiological Studies, 37(4), 53-59.

Rosaeg MV, Sindre H, Persson D, Breck O, Knappskog D, Olsen AB, Taksdal T (2017) Ballan wrasse (*Labrus bergylta* Ascanius) is not susceptible to pancreas disease caused by salmonid alphavirus subtype 2 and 3. J Fish Dis, 40(7), 975-978.

Rozas-Serri M, Ildefonso R, Peña A, Enríquez R, Barrientos S, Maldonado L (2017) Comparative pathogenesis of piscirickettsiosis in Atlantic salmon (*Salmo salar* L.) post-smolt experimentally challenged with LF-89-like and EM-90-like *Piscirickettsia salmonis* isolates. Journal of Fish Diseases.

Ruane NM, Swords D, Morrissey T, Geary M, Hickey C, Collins EM, Swords F (2018) Isolation of salmonid alphavirus subtype 6 from wild-caught ballan wrasse, *Labrus bergylta* (Ascanius). Journal of Fish Diseases, 41(11), 1643-1651.

Rønneseth A, Haugland GT, Colquhoun D, Wergeland HI (2014) Utvikling av smittemodeller på oppdrettet rognkjeks. FHF - The Norwegian Seafood Research Fund. University of Bergen, FHF Report 1-2014.

Sanchez JC, Mancilla J, Hevia M, Saez PJ (2018) The Patagonian blenny (*Eleginops maclovinus*): a Chilean native fish with potential to control sea lice (*Caligus rogercresseyi*) infestations in salmonids. Pp. 468-482. In: Treasurer J. (Ed.)Cleaner fish biology and aquaculture applications. 5M Publishing Ltd. 519 pp.

Sandlund N, Gjerset B, Bergh O, Modahl I, Olesen NJ, Johansen R (2014) Screening for Viral Hemorrhagic Septicemia Virus in Marine Fish along the Norwegian Coastal Line. PLoS One, 9(9).

Sandvik H, Gederaas L, Moen TL, Skjelseth S (2015) Veileder fremmede arter 2017: risikovurdering av økologisk påvirkning, versjon 0.9, Artsdatabanken, Trondheim.

Sayer MDJ, Gibson RN, Atkinson RJA (1996) Growth, diet and condition of corkwing wrasse and rock cook on the west coast of Scotland. Journal of Fish Biology 49, 76–94.

Sayer MDJ, Gibson RN, Atkinson RJA (1995) Growth, diet and condition of goldsinny on the west coast of Scotland. Journal of Fish Biology 46, 317–340.

Sayer MDJ, Treasurer JW (1996) North European wrasse: identification, distribution and habitat. In: Wrasse: biology and use in Aquaculture. (eds M.D.J. Sayer, M.J. Costello and J.W. Treasurer). Oxford: Fishing News Books, pp 3–12.

Scalera R. et al. 2012.The impacts of invasive alien species in Europe, EEA Technical report No 16/2012

Scholz F, Ruane NM, Morrissey T, Marcos-Lopez M, Mitchell S, O'Connor I, Rodger HD (2018) Piscine myocarditis virus detected in corkwing wrasse (*Symphodus melops*) and ballan wrasse (*Labrus bergylta*). Journal of Fish Diseases, 41(1), 147-152.

Seljestad GW (2019) " A cleaner break"-Genetic analysis identifies two major groups of ballan wrasse (*Labrus bergylta*) within Scandinavia and evidence of phenotype derived divergence. Master's thesis, The University of Bergen.

Shi W, Wang Y, Ren X, Gao S, Hua X, Guo M, Liu M (2018) EvaGreen-based real-time PCR assay for sensitive detection of salmonid alphavirus. Mol Cell Probes, 39, 7-13.

Skiftesvik AB, Bjelland R, Durif CMF, Halvorsen KT, Shema S, Fields D, Browman H (2017) Program rensefisk: Kunstig lys og rensefisk. Final FHF report project 901146. Fisken og Havet, 1–43.

Skiftesvik AB, Bjelland R, Durif CMF, Moltumyr L, Hjellum RB, Halvorsen KT (2018) Cleanerfish program: Behaviour and species interactions in the seacages. Final FHF report project 900978. Fisken og Havet, 1–61.

Skiftesvik AB, Bjelland RM, Durif CMF, Johansen IS, Browman HI (2013) Delousing of Atlantic salmon (*Salmo salar*) by cultured vs. wild ballan wrasse (*Labrus bergylta*). Aquaculture 402, 113–118.

Skiftesvik AB, Blom G, Agnalt A-L (2014a) Wrasse (Labridae) as cleaner fish in salmonid aquaculture – The Hardangerfjord as a case study. Marine Biology Research 10, 289–300.

Skiftesvik AB, Durif CMF, Bjelland RM, Browman HI (2014b) Distribution and habitat preferences of five species of wrasse (family Labridae) in a Norwegian fjord. ICES Journal of Marine Science 72, 890–899.

Skilbrei OT, Heino M, Svåsand T (2014) Using simulated escape events to assess the annual numbers and destinies of escaped farmed Atlantic salmon of different life stages from farm sites in Norway. ICES Journal of Marine Science, 72(2), 670-685.

Skoge RH, Brattespe J, Okland AL, Plarre H, Nylund A (2018) New virus of the family Flaviviridae detected in lumpfish (*Cyclopterus lumpus*). Arch Virol, 163(3), 679-685.

Småge SB, Frisch K, Brevik ØJ, Watanabe K, Nylund A (2016) First isolation, identification and characterisation of *Tenacibaculum maritimum* in Norway, isolated from diseased farmed sea lice cleaner fish *Cyclopterus lumpus* L. Aquaculture, 464, 178–184.

Snow M, Black J, Matejusova I, McIntosh R, Baretto E, Wallace IS, Bruno DW (2010) Detection of salmonid alphavirus RNA in wild marine fish: implications for the origins of salmon pancreas disease in aquaculture. Diseases of Aquatic Organism; 91(3), 177-188.

Sotka EE (2005) Local adaptation in host use among marine invertebrates. Ecology Letters, 8, 448-459.

Stagg HEB, Guðmundsdóttir S, Vendramin N, Ruane N, Sigurðardóttir H, Christiansen DH, Olesen NJ (2017). Isolation and characterisation of a new ranavirus isolated from lumpfish in the north Atlantic area. In Proceedings of The 4th Ranavirus symposium.

Steigen A, Nylund A, Plarre H, Watanabe K, Karlsbakk E, Brevik O (2018) Presence of selected pathogens on the gills of five wrasse species in western Norway. Diseases of Aquatic Organisms 128, 21-35.

Steinum TM, Karataş S, Martinussen NT, Meirelles PM, Thompson FL, Colquhoun DJ (2016) Multilocus sequence analysis of close relatives *Vibrio anguillarum* and *Vibrio ordalii*. Applied and Environmental Microbiology, 82(18), 5496–5504.

Sundt-Hansen LE, Huisman J, Skoglund H, Hindar K (2015) Farmed Atlantic salmon *Salmo salar* L. parr may reduce early survival of wild fish. Journal of Fish Biology; 86:1699-1712.

Sveier H, Breck O (2018) Cleaner fish application in Norway. Pp. 359-369. In: Treasurer J. (Ed.) (2018) Cleaner fish biology and aquaculture applications. 5M Publishing Ltd. 519 pp.

Sørensen UBS, Larsen JL (1986) Serotyping of *Vibrio anguillarum*. Applied and Environmental Microbiology, 51(3), 593–597.

Thangstad T (1999) Spatial and temporal distribution of three wrasse species ( Pisces : Labridae ) in Masfjord , western Norway : habitat association and effects of environmental variables.

Thompson JR, Pacocha S, Pharino C, Klepac-Ceraj V, Hunt DE, Benoit J, Polz MF (2005) Genotypic diversity within a natural coastal bacterioplankton population. Science; 307, 1311–1313.

Treasurer JW (1997) Parasites of wrasse (Labridae) in inshore waters of west Scotland stocked as cleaner fish of sea lice (Caligidae) on farmed Atlantic salmon. Journal of Fish Biology 50, 895-899.

Treasurer JW (2002) A review of potential pathogens of sea lice and the application of cleaner fish in biological control. Pest Management Science 58, 546-558.

Treasurer JW (2012) Diseases of north European wrasse (Labridae) and possible interactions with cohabited farmed salmon, *Salmo salar* L. Journal of Fish Diseases, 35(8), pp. 555-562.

Treasurer JW (2018) An introduction to sea lice and the rise of cleaner fish. Cleaner Fish Biology and Aquaculture Applications. In: Treasurer JW, ed. Cleaner fish biology and aquaculture applications. Sheffield: 5M Publishing Ltd, 3–24.

Uglem I, Rosenqvist G, Wasslavik HS (2000) Phenotypic variation between dimorphic males in corkwing wrasse. Journal of Fish Biology 57, 1–14.

Valheim M, Hastein T, Myhr E, Speilberg L, Ferguson HW (2000) Varracalbmi: a new bacterial panophthalmitis in farmed Atlantic salmon, Salmo salar L. Journal of Fish Diseases, 23(1), 61–70.

Villegas-Ríos D, Alós J, March D, Palmer M, Mucientes G, Saborido-Rey F (2013) Home range and diel behavior of the ballan wrasse, *Labrus bergylta*, determined by acoustic telemetry. Journal of Sea Research 80, 61–71.

VKM, Rimstad R, Basic D, Gulla S, Hjeltnes B, Mortensen S (2017) Risk assessment of fish health associated with the use of cleaner fish in aquaculture. Opinion of the Panel on Animal Health and Welfare of the Norwegian Scientific Committee for Food and Environment. VKM report 2017:32, ISBN: 978-82-8259-289-5, ISSN: 2535-4019. Norwegian Scientific Committee for Food and Environment (VKM), Oslo, Norway

Walker B, Steffen W (1997) An overview of the implications of global change for natural and managed terrestrial ecosystems. Conservation Ecology, 1 (2): 2.

Waples RS (1991) Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific North West. Canadian Journal of Fisheries and Aquatic Sciences, 48, 124-133.

Waser NM (1993) Sex, mating systems, inbreeding, and outbreeding. In: The Natural History of Inbreeding and Outbreeding: Theoretical and Empirical Perspectives (ed. N.W. Thornhill), 1-13. University of Chicago Press, Chicago.

Wessel O, Braaen S, Alarcon M, Haatveit H, Roos N, Markussen T, Rimstad E (2017) Infection with purified Piscine orthoreovirus demonstrates a causal relationship with heart and skeletal muscle inflammation in Atlantic salmon. PLoS One, 12(8), e0183781.

Westin L, Nissling A. 1991. Effects of salinity on spermatozoa motility, percentage of fertilized eggs and egg development of Baltic cod (Gadus morhua), and implications for cod stock fluctuations in the Baltic. Mar Biol., 108, 5-9.

Whittaker BA, Consuegra S, Garcia de Leaniz C (2018) Genetic and phenotypic differentiation of lumpfish (*Cyclopterus lumpus*) across the North Atlantic: implications for conservation and aquaculture PeerJ 6:e5974.

Wickham, H. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016.

Wiik-Nielsen CR, Lovoll M, Sandlund N, Faller R, Wiik-Nielsen J, Bang Jensen B (2012) First detection of piscine reovirus (PRV) in marine fish species. Diseases of Aquatic Organisms, 97(3), 255-258.

Wittwer C, Treasurer J (2018) Egg collection by hand-stripping and natural spawning of lumpfish *Cyclopterus lumpus* broodstock. In: Treasurer JW, ed. Cleaner fish biology and aquaculture applications. Sheffield: 5M Publishing Ltd, 147-160.

Woll AK, Bakke S, Aas GH, Solevåg SE, Skiftesvik AB, Bjelland RM (2013) Velferd leppefisk i merd. Rapport MA 13-07. Høgskolen i Ålesund.