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REVIEW ARTICLE

The development of the Norwegian wrasse fishery and the use of wrasses as cleaner fish in the salmon aquaculture industry

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Abstract Norway leads the world aquaculture production of Atlantic salmon *Salmo salar* and farmed Norwegian Atlantic salmon is currently consumed around the globe. However, sea lice infestation is a major problem faced by the salmon aquaculture industry in Norway and elsewhere. The use of wild-caught cleaner fish, mainly wrasses, has been recommended over the other available methods as the most economical and environmentally friendly option to control sea lice infestation in salmon farming. Here, we review the development of the Norwegian wrasse fishery and the use of wrasses as cleaner fish. In this document, we address the sea lice problem and introduce the main wrasse species employed as cleaner fish, document the cleaning behaviour of wrasses, present the development of a new wrasse fishery associated with the salmon aquaculture industry, and finally, we identify the main challenges associated with the intensive use of wild-caught cleaner wrasses and provide some insight for future directions of the wrasse fishery and further development of aquaculture techniques to supply salmon facilities with domesticated cleaner fish.

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The problem of sea lice infestation in Atlantic salmon aquaculture in Norway

Atlantic salmon *Salmo salar* is one of the most important aquaculture species in the world representing 8.5% of the total global value, approximately $13 billion [1]. In addition to hosting the largest wild populations [2], Norway leads the world production of farmed Atlantic salmon with 1.2 million tons in 2014 [3]. Most on-growing salmon farms in Norway are open sea cages [4, 5]. However, the expansion of the Atlantic salmon aquaculture in Norway since the 1970s has not been exempt from controversy regarding degradation of marine ecosystems [6]. Major technological and environmental challenges with salmon aquaculture include eutrophication and environmental pollution; ecological and genetic interactions between escaped farmed fish and wild stocks; spread of parasites and diseases; or the need to develop better infrastructure to minimize physical damage of the sea cages [5, 7–9]. The magnitude of the sea lice problem is such that Norwegian authorities subjected further growth of salmon aquaculture to solving, or at least considerably reducing, the problems of sea lice infestation [3].

Soon after the establishment of the Norwegian farms, the sea louse emerged as a major problem [2, 4]. Sea louse is the common name given to two species of ectoparasites commonly found on Atlantic salmon: *Lepeophtheirus salmonis* and *Caligus elongatus*. *L. salmonis* is a parasitic copepod known for infecting salmonid fishes from the genera *Salvelinus*, *Oncorhynchus* and *Salmo* in the Northern Hemisphere [2, 10]. Meanwhile, *C. elongatus* is a more generalist species and its infestation has been recorded in more than 80 species [11], including both salmonids and non-salmonids [12]. Usually, farmed Atlantic salmon is initially infested by *C. elongatus* while infestation by *L. salmonis* occurs at a later stage [13]. Sea lice infestation is light-dependent and often associated with shallow coastal waters; although many other factors including temperature, season or the developmental stage and physiological condition of the host may influence lice infection [2, 4, 10, 13–15]. While moderate sea lice infection often causes negative effects on growth and survival, heavily infected individuals have a high chance of stress-related mortality [15]. In fact, sea lice infestation is a major cause of mortality and economic loss in farmed Atlantic salmon with production value loss estimated between 4 and 10% of the fish [16]. In Norway, there is a legal limit of 0.5 adult female lice per fish, above this level a treatment must start within a fortnight [2]. In 2015, the overall costs for sea lice control in the country was estimated to surpass 5 billion Norwegian Kroner (over 500 million €, [17]). Current prevention and treatment measures against sea lice infestation in Norwegian salmon farms include: (1) administration of medicines orally, (2) bathing the fish in an enclosed system with chemicals, and, (3) biological treatment by introducing cleaner fish into the cages that feed on sea lice [18, 19]. Alternative mechanical treatments using warm water have been proposed recently; however, this new approach is still in the infancy stage of development, and further improvements are needed before it is extensively used [20]. Here, we use the term cleaner fish to refer to both wrasses and lumpfish *Cyclopterus lumpus*, while we refer to cleaner wrasses when lumpfish is excluded from the context. The use of cleaner fish in the biological control of sea lice infestation has been recommended over other methods as the most economical and environmentally friendly option [19, 21]. Some of the advantages of using cleaner fish over alternative approaches include the fact that wrasses (1) help to keep sea lice numbers low without risk for human health; (2) can be co-cultured with salmon that do not suffer additional stress even under non-optimal health condition; (3) can feed on sea lice continuously, even at small densities; (4) are not toxic for the environment; and (5) sea lice cannot develop resistant mechanisms against cleaner wrasses [21–23], although there may be increased selection pressure for lice to better evade predation by cleaner fish.

Here, we review the development of the Norwegian wrasse fishery (Fig. 1) and the use of wrasses as cleaner fish by the Atlantic salmon industry in Norway. We introduce the main wrasse species employed as cleaner fish and their cleaning behaviour. We present the development of a new wrasse fishery associated with the salmon aquaculture industry and the establishment of fisheries regulations. Finally, we identify the main challenges associated with the intensive use of wild-caught cleaner wrasses and provide

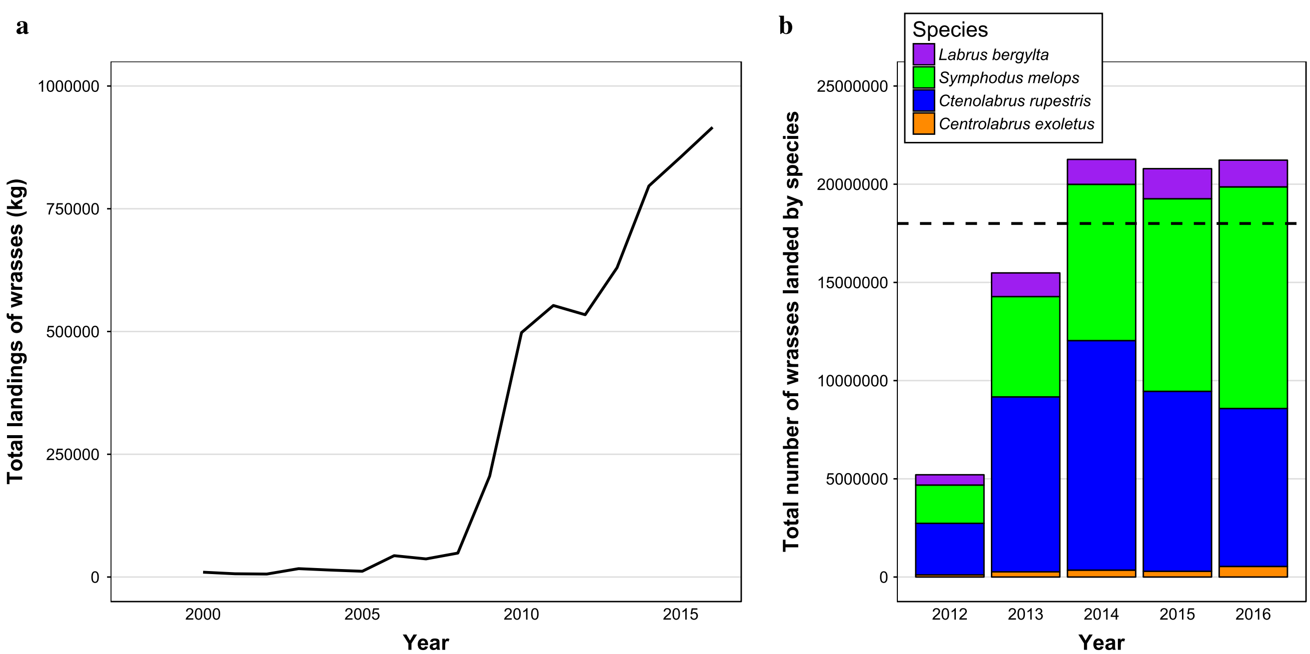

Fig. 1 **a** Annual variation in total landings of wrasses (in kg) reported in Norway during the period 2000–2016. **b** Total number of specimens of the four main wrasse species used in Norwegian salmon farms landed during the period 2012–2016. The dashed black line represents the maximum fishing quota set up at 18 million fish (Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Yrkesfiske/Tema/Leppefisk, "Accessed 17 January 2017")

some insight for future directions of the wrasse fishery and further development of aquaculture techniques to supply salmon facilities with domesticated cleaner fish.

Cleaner wrasse species used in the salmon aquaculture

Among the 208 fish species documented to display symbiotic cleaning behaviour [24], biological treatment against sea lice infestation in Norwegian salmon farms relies on the use of five main species as cleaner fish, namely: corkwing *Symphodus melops*, goldsinny *Ctenolabrus rupestris*, ballan *Labrus bergylta* and rock cook *Centrolabrus exoletus* wrasses (Fig. 2), and lumpfish *Cyclopterus lumpus* to a lesser extent [22, 25] (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk/, "Accessed 17 January 2017"). Initial trials also tested the cleaning behaviour of cuckoo wrasse *Labrus mixtus*; however, this species is no longer targeted [25]. In this review, we focus on the four wrasses currently used as cleaner fish.

All four species belong to the family Labridae, one of the largest fish families [26]. Each species presents unique colour patterns and morphological features, which make it easily differentiated from the other cleaner wrasses [27–30], while they also share some common attributes. All species are commonly observed inhabiting shallow rocky areas along the Northeast Atlantic, and Norway stands at the northern limit of their distribution range [29–31]. Their abundance in Norwegian waters has increased in recent times in connection to the increase in sea water temperatures [33, 34]. The spawning season for cleaner wrasses in Norway extends from spring until late summer [27, 31, 35, 36]. Metabolic activity of all four wrasses is correlated to sea water temperature above 10 °C and daylight hours [31, 37]. During winter periods, when sea water temperature falls below 6–8 °C, they are hardly seen and enter a hypometabolic state [37, 38]. Goldsinny is the cleaner wrasse species coping best with rapid temperature and salinity reductions [38–40]. Experimental trials revealed high mortality rates of corkwing and rock cook wrasse below 4 °C [39, 41]. In addition to the above-mentioned common attributes, each species presents additional features in its life history of particular relevance for the development of the fishery.

Corkwing wrasse *Symphodus melops*

Corkwing wrasse (Fig. 2a), known as grønngylt in Norwegian is, together with goldsinny, the most abundant cleaner wrasse species used by the Atlantic salmon farming industry in Norway (Fig. 1b). It can live nine years, attain 28 cm in total length and reach maturity after 1–3 years [27, 30]. The species display sexual size dimorphism with nesting males being significantly larger in total lengths than females and sneaker males [42, 43]. These differences in sexual size dimorphism were especially remarkable in specimens collected from the west coast of Norway, and it has been ascribed to a delay in maturation and faster growing of nesting males with respect to females and sneaker males [42]. The phenotypic differences observed between corkwing wrasse populations inhabiting the western and the Skagerrak coast of Norway are in agreement with recent genetic data evidencing sharp regional differences [44]. Blanco Gonzalez et al. [44] suggested the presence of unsuitable sandy areas for reproduction and oceanographic factors as major barriers for population connectivity in this species in Norway.

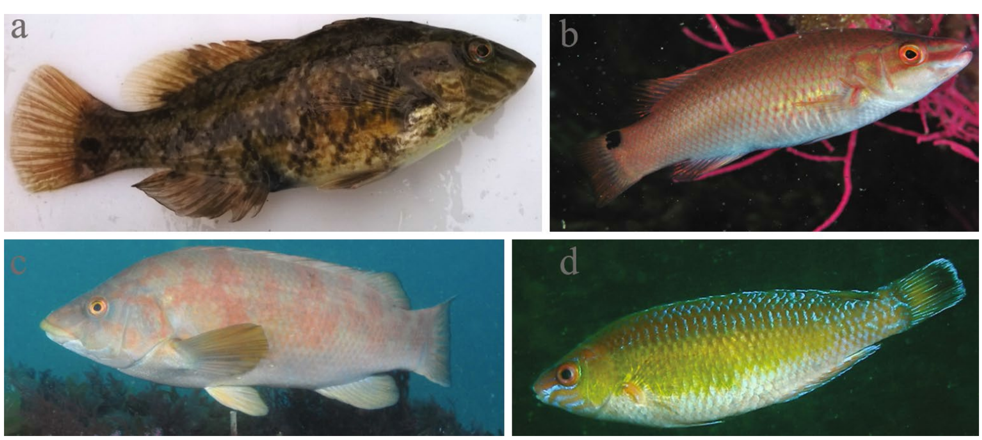

Fig. 2 Wrasse species used as cleaner fish in the Norwegian salmon aquaculture. **a** female corkwing *Symphodus melops*, **b** goldsinny *Ctenolabrus rupestris*, **c** ballan *Labrus bergylta*, **d** rock cook *Centrolabrus exoletus*

Goldsinny wrasse *Ctenolabrus rupestris*

Goldsinny (Fig. 2b), known as bergnebb in Norwegian, is the most abundant cleaner wrasse species in central and northern areas of Norway. It is also the smallest of the cleaner wrasses found in Norway, usually attaining 10–12 cm total length, with a maximum of 15–18 cm [30, 31, 35] and maximum age of 14 and 20 years for males and females, respectively [43, 45]. The species reach maturity after 1–2 years [27, 30]. Males grow faster than females [30, 42, 43, 46] while nearby populations in the Norwegian Skagerrak coast have shown also significant spatial differences in growth trajectories [47]. In contrast to the benthic eggs described in the other cleaner wrasses, goldsinny is the only species releasing planktonic eggs [27, 30]. As adults, goldsinny display high site fidelity and invest significant time defending very small territories [46, 48]. Limited adult migration and spawning site fidelity were suggested to explain recent patterns of genetic isolation by distance detected in Norwegian population of goldsinny wrasse [49].

Ballan wrasse *Labrus bergylta*

Ballan wrasse (Fig. 2c), known as bergylt in Norwegian, is the largest wrasse species found in northern Europe [27, 28]. It is the fastest growing wrasse and it can attain 60 cm in total length and live up to 29 years [30, 50]. The larger size attained and its robustness compared to other wrasses makes ballan wrasse very valuable to delouse larger salmons [51]. Currently, it is also the only wrasse species farmed, although aquaculture production is low (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"). Ballan wrasse display a high variety of body colouration with two major colour patterns, plain and spotted [52]. These two morphotypes differs in life history traits such as growth, maturation and mortality rates [53, 54] and a taxonomic re-evaluation of the species has been proposed [55]. To date, knowledge of genetic population structure of ballan wrasse in Norway is limited to a couple of studies analysing mitochondrial DNA polymorphism on a few individuals from the southern coast [56, 57], which makes it difficult to draw conclusions about the impact of the fishery and fish translocations on the genetic diversity.

Rock cook *Centrolabrus exoletus*

Rock cook wrasse (Fig. 2d), known as grasgylt/gressgylt in Norwegian, is the least common species used as cleaner fish in Norway (Fig. 1), and its biology is still poorly documented [27, 30]. The species can attain 19 cm in body length and live up to 9 years [27, 30, 31]. Males grow faster than females [43]. To date, no study has focused on characterizing the genetic resources of this species in Norway.

Wrasses as cleaner fish

First observations of cleaning behaviour among wrasses inhabiting the Northeast Atlantic were documented by Potts [58] who observed corkwing, goldsinny and rock cook wrasse removing parasitic gnathiid larvae from the body of several host fish, most commonly the pink bream *Pagellus centrodontus*, kept in a public aquaria. Later on, Hillden [48] corroborated the cleaning behaviour of goldsinny wrasse from field observations. These observations inspired Bjordal [59] to pioneer the use of cleaner wrasses in salmon farms in Norway. The promising results achieved encouraged the development of new experiments and full scale trials on tanks and sea cages over the next years (reviewed by Bjordal [60]). Since then, significant efforts have been directed towards understanding the cleaning behaviour and effectiveness of wrasses as biological treatment against sea lice infestation [27, 30]. Wrasse species used by the salmon aquaculture industry present significant differences in life history traits, which make them suitable under different environmental conditions and at different stages during the salmon production [25, 30, 36]. In terms of number of fish, goldsinny and corkwing wrasse are the two main species used in Norwegian salmon fish farms (Fig. 1b, Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"). Small goldsinny and rock cook wrasses are preferred during early the salmon post-smolt phase, while larger corkwing and especially ballan wrasse are more suitable for larger salmon up to 3–5 kg [36]. Indeed, only corkwing and ballan wrasse grow large enough to delouse salmon during their second year in net pens, as smaller goldsinny and rock cook would be eaten by salmon [25]. The recommended size ranges of cleaner wrasses in salmon farms is between 10 and 25 cm [61]. Temperature tolerance is of major concern, as all cleaner wrasses in Norway are at the northern limit of their distribution range [28, 32]. The ability to enter a hypometabolic torpor state infers goldsinny have better tolerance and lower mortality under low winter temperatures (below 4 °C) than corkwing and rock cook wrasse [37, 38].

Wrasses perform a size control delousing on salmon by preying on larger adult sea lice; however, they have shown limitations to visualize and remove the smaller chalimus stage lice [13, 22, 25, 61]. Goldsinny wrasse has shown a good appetite for sea lice soon after being released into salmon sea cages [60]. Gut content analysis revealed that a single goldsinny can consume up to 58 sea lice per day

[22, 60], twice as many as ballan wrasse [25]; although, not all fish performed cleaning [60]. Each species display differences in diel feeding activity, the peak in goldsinny was recorded at mid-day, a bit earlier than in ballan wrasse, while corkwing wrasses feed more actively at dawn [22, 37, 62]. Keeping ratios up to 100–150 salmon per wrasse have proven very effective to control sea lice infestation below the maximum limit permitted in Norwegian salmon farming [22, 25, 60, 61]. Commercial farms are recommended to use a ratio of 5% wrasses, although this ratio may vary based on the level of sea lice infestation, the species of cleaner wrasse employed, as well as the amount of alternative food (i.e., excess of pellets, fouling organisms in the net pens, and dead salmon at the bottom) available [22, 25, 60]. There are additional factors to be taken into account when estimating the number of wrasses to be released in the salmon farms. It may be difficult to maintain healthy wrasses during prolonged periods with female wrasses being particularly sensitive to handling during the spawning season [63]. A significant number of small wrasses may escape through the nets or be eaten by salmon during the deployment operation [60]. Losses in relation to intra- and interspecific aggressiveness should be also considered [22, 25, 27, 59, 60, 64, 65]. A large number of wrasses have been reported to die lifting the nets during routine cleaning operations in the farms [59]. In this regard, ballan wrasse has been postulated as the most robust species and present the greatest potential for large-scale biological delousing [51, 66, 67]. Parasites and disease may be another cause for large mortalities in wrasses (for detailed information see [21, 68, 69]).

The development of the wrasse fishery

After the successful experiments conducted by Bjordal [59], in 1988, goldsinny became the first wrasse species targeted commercially in Norway, an initiative adopted a year later in the British Islands [30, 43, 60]. Later, corkwing wrasse, juvenile ballan and rock cook wrasses were also targeted [25]. The development of the wrasse fishery in Norway was triggered by the restrictions regarding the use of drugs against sea lice [70]. During the early days of the wrasse fishery, salmon farmers barely used 1000 wrasses, a number that increased steadily to reach 3.5 million in 1997 [71]. The beginning of the fishery along the southern Skagerrak coast of Norway was delayed a few years. In contrast to the densely covered western coast, salmon farms along the Skagerrak coast are scarce. Thus, the favourable environmental conditions for temperate wrasses in the latter region [33] contrast with their limited demand. The excess of wrasses available in the Skagerrak resulted in high number of fish been translocated to northern regions where local stocks were not large enough to support the high demand of wrasses from salmon farms. In 1996, as many as 800,000 goldsinny wrasses fished in the Skagerrak were delivered to salmon farms located in the west coast [71], which suggest that the number of fish initially caught was considerably larger after taking fish mortality into account [72]. In the late 1990s, the demand of wrasses declined, in line with the development of new chemotherapeutical treatments to combat sea lice infestation. However, the reduction in fishing pressure on wrasses did not last long as sea lice showed signs of resistance to chemotherapeutants [73]. These mishap episodes in combination with the expansion of the salmon aquaculture industry generated a renewed interest in cleaner wrasses and, since 2009, the number of wrasses used in the farms has been boosted dramatically to exceed 21 million in 2016 (Fig. 1b, Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017") with most farms using them. Most of the cleaner wrasses are adults of wild origin, except a small proportion of farmed ballan wrasse representing less than 15% of the total (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"). While salmon farms in the west coast use local wrasse populations, fish farms in central and northern Norway continue relying on translocated wrasses from the Skagerrak coast of Norway and Sweden. Therefore, the wrasse supply chain in Norway present two variants: in the west coast, fishers deliver their catches directly to salmon farms; while those operating in the Skagerrak coast sell the wrasses to intermediary companies who will transport the fish alive in trucks and deliver them to the farms located in the west. Nowadays, the wrasse fishery is regarded as very lucrative and cleaner wrasses have become a major income for the coastal fishing fleet in the south coast of Norway [31, 74]. In fact, during the wrasse fishing season, fishers tend to be dedicated exclusively to catching wrasses, targeting other species off-season.

Prior to the development of the fishery, wrasses were fished as by-catch; however, the need for catching and keeping healthy fish alive required the development of specific gear, which turned out to be collapsible lantern-shaped baited pots and different designs of fyke nets like those used to catch eels [75]. Recently, modified wrasse pots seem to be the choice of most fishermen in the west coast, while those in the south coast keep using fyke nets [63]. The way to report the number of wrasses used by fish farmers to the Norwegian Directorate of Fisheries has also changed over time (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"). It was not until 1998 that the data was organized by county (region). In addition, the number of wrasses used in the farms was simply reported as "wrasses", despite the data comprised four different species. At that time, wrasse landings were reported in gross weight (kg) which was then converted to numbers following official conversion factors of 0.045, 0.024, 0.123 and 0.020 for corkwing, goldsinny, ballan and rock cook, respectively [63]. Since 2013, data are reported in numbers, separated for each of these species.

Norwegian wrasse fishery regulations

Despite the intensive fishing pressure, management regulations for the wrasse fishery were not introduced until 2011. At that time, the Directorate of Fisheries established a minimum size of 11 cm for all wrasse species and determined the extent of the fishing season, setting up a fishing closure in Spring as a mean to protect spawning stocks. These two measures have been recently refined and, in 2015, new regulations established minimum sizes for corkwing and ballan wrasse to 12 and 14 cm, respectively. The period of fishing closure has been extended progressively and currently the fishing session extends from July 6th at 8:00 a.m. until September 6th and 9th at 20:00 for the south and west coast, respectively (Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Yrkesfiske/Tema/Leppefisk, "Accessed 17 January 2017"). In central Norway, above 62°N, the season starts on July 25th, and it is closed on September 23rd. Regulations enforce the use of an escape opening of at least 12 × 70 mm fitted in the gear to reduce catches below the legal size. Last year, in 2016, a maximum fishing quota for wrasses was set for the first time, at 18 million. This number was distributed between the southern, western and central part of the country setting their limits at 4, 10 and 4 million wrasses, respectively. An additional major measure adopted recently limits recreational fishers to catch and sell wrasses for a value up to 50,000 NOK per year using a maximum of 20 fyke nets or pots, and all catches must be registered. Previously, wrasses caught by recreational fishers were outside the fishery regulation, which represented a major challenge for management and offered these groups of fishers an opportunity to earn significant amounts of money [63]. Commercial fishers can use up to 100 fyke nets or pots in the southern coast, with no restrictions in western and northern areas. In addition to these regulations, fish farms may ask for additional demands when purchasing the wrasses. Some of the common demands from salmon farms include larger size limits and preference for active territorial males over females and sneaker males as they have proven more aggressive and less vulnerable to wounds and mortality during handling and transportation [25, 47, 76].

Challenges and future perspectives

The development of the wrasse fishery has contributed significantly to combat the sea lice problem in the Norwegian salmon aquaculture industry, and it is likely that it will continue helping the fight against sea lice. Although cleaner wrasses will probably never eradicate the parasites completely, they can assist fish farmers to remove and control sea lice infestation, keeping lice numbers below the legal limit [22, 25, 60]. The abundance and cleaning behaviour of wrasses are correlated to mild temperatures, below 10 °C they reduce their metabolic activity while mortality below 4 °C can be very high [30, 37–41]. Although wrasses are the species of choice in southern and central Norway; temperature constraints make them unsuitable for salmon farms located in northern regions, where better adapted lumpfish appear as a cold-water alternative [65, 67]. Currently, major efforts are directed towards increasing lumpfish production; however, Imsland et al. [67] observed that stocking densities of lumpfish should double or triple those of wrasses in order to achieve the same efficiency for sea lice removal. Hence, translocations of wrasses from the southern Skagerrak coast to the salmon farms located in the west and central coasts of Norway will likely continue, even though basic knowledge on the species biology and ecology is still very poor.

Genetic studies on the two main cleaner wrasses used in the salmon industry, goldsinny [77, 78] and corkwing wrasse [44], found strong population structure along the Norwegian coast with a major genetic break between western and Skagerrak populations. Microsatellite genetic markers suggested further population structuring among corkwing wrasse populations from western Norwegian fjords [44]. Western and Skagerrak wrasses have also shown significant differences in life history traits such as growth rates, size-at-maturity, sex ratio and age-at-maturity [25, 31, 32, 42, 47]. Thus, the regional intraspecific differences in genetics and life history traits has raised concerns about the adaptive and evolutionary potential of the species [79, 80]; particularly, after preliminary results of an ongoing project studying the adaptive potential of translocated corkwing wrasse revealed successful interbreeding between western and Skagerrak individuals (Blanco Gonzalez et al., unpubl data, 2017, https://corkwingadapt.wordpress.com/). A recent study on goldsinny [49] did not find a major genetic break between western and Skagerrak populations, but rather a pattern of isolation by distance. On the other hand, they suggested that fish translocations were responsible for the genetic similarities observed between one sample from mid-Norway and those collected from the Skagerrak.

Fish health and welfare are other major concerns associated with wrasse translocations [21, 68, 69, 81]. Several studies have investigated mortalities in relation to bacterial, viral and parasitic diseases in cleaner wrasses, and possible interactions between wrasses and farmed salmon [21, 68, 69]; however, no study has provided evidence that wrasses act as a vector of disease in salmon [21]. Despite significant advances over recent years, improvements of wrasse welfare during fishing and transportation operations as well as during the time in net cages remains one of the main challenges currently faced by the salmon industry [81, 82].

Recently adopted management regulations (Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Yrkesfiske/Tema/Leppefisk, "Accessed 17 January 2017") confirm the increasing concerns of fisheries authorities regarding the sustainability of the wrasse fishery. Thus, the inclusion of species-specific size limits and shorter fishing seasons after taking into consideration the life-history of the species, limiting the access of recreational fishers and establishing regional quotas and the incorporation of an escape opening fitted in the gear are significant steps towards achieving sustainable fishing and avoiding overfishing. One key area where significant research is still needed is to better understand the fate of discharged undersized wrasses, as fishing mortality may be considerably higher than anticipated [72]. In addition, the Norwegian wrasse fishery is sex- and size-selective, a fact that may compromise the viability of the fishery further [47, 83, 84]. Recently, Halvorsen et al. [84] compared catch-per-unit-effort (CPUE) between Marine Protected Areas (MPAs) and control areas open for fishing and reported significantly higher CPUE within MPAs, 33–65% in goldsinny and 16-92% in corkwing wrasse. They also found larger and older corkwing wrasse within MPAs. While these observations suggest that the fishery have considerable negative impacts on target populations and that small MPAs can help to protect the stock composition and high abundances, their conclusions should be interpreted carefully. The study was performed in August and September [84], at the end of the fishing season for wrasses (Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Yrkesfiske/Tema/Leppefisk, "Accessed 17 January 2017"). Considering the limited dispersal ability of both species [46–48] and the sex- and size-selectivity of the fishery [47, 84], it is likely that, in the control areas opened to the fisheries, larger individuals, particularly males, were fished before the study started and, therefore, the positive effects of the MPAs overestimated. Winter storage of wrasses when salmon cages are emptied could help to reduce fishing pressure and have them available soon after salmon are introduced into the sea cages [39]. However, there are concerns about the possibility that stored wrasses may be infected with sea lice. Re-using wrasses in consecutive years may re-introduce parasitic sea lice; therefore, this option is not recommended. Instead, wrasses are intentionally released to the marine environment after they have been used for one season [82], and replaced with newly caught wild wrasse, keeping the annual demand of wrasses high.

Future development of aquaculture techniques to produce domesticated wrasses as an alternative to reduce fishing pressure of wild stocks and risks associated with fish translocations is unclear. Earlier breeding trials with corkwing, goldsinny and rock cook brought promising results [85, 86]; however, current commercial rearing techniques are limited to ballan wrasse [61] and the volume of farmed ballan wrasses supplied is low (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"). The fact that wrasses need long periods before they can be deployed with salmon and that they [87] fall into a hypometabolic state at low temperature [37, 38] stimulated the interest in alternative species which could keep feeding on sea lice during the cold winter, such as the lumpfish (see review by Powell et al. [88]). Indeed, although the number of companies and licenses to produce cleaner fish has increased considerably in the last five years, in 2015 there were 18 companies and 45 licenses (Statistics Norwegian Directorate of Fisheries: http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Akvakulturstatistikk-tidsserier/Rensefisk, "Accessed 17 January 2017"), most of them are intended to produce lumpfish. Recent advances in aquaculture techniques of lumpfish [65, 66, 88] make hatchery-produced lumpfish an alternative to combat sea lice infestation, especially in northern salmon farms, in upcoming years [88].

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