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ORIGINAL ARTICLE

# Impact of harvesting cleaner fish for salmonid aquaculture assessed from replicated coastal marine protected areas

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**ABSTRACT**
Wrasse (Labridae) fisheries have increased markedly in Norway since 2010. Wrasse are being used as cleaner fish in salmonid aquaculture to control sea-lice infestations. However, fundamental knowledge on the demography and abundance of the targeted wrasse populations in Norwegian waters is lacking, and the consequences of harvesting at the current intensity have not been assessed. Here, we compared catch per unit effort (CPUE), size, age and sex ratio of goldsinny wrasse (*Ctenolabrus rupestris*) and corkwing wrasse (*Symphodus melops*) between marine protected areas (MPAs) and control areas open for fishing at four localities on the Skagerrak coast in Southern Norway. The CPUE of goldsinny larger than the minimum size limit was 33–65% higher within MPAs, while for corkwing three of four MPAs had higher CPUE with the relative difference between MPAs and control areas ranging from −16% to 92%. Moreover, corkwing, but not goldsinny, was significantly older and larger within MPAs than in control areas. Sex ratios did not differ between MPAs and control areas for either species. Our study suggests that despite its short history, the wrasse fisheries have considerable impacts on the target populations and, further, that small MPAs hold promise as a management tool for maintaining natural population sizes and size structure. Goldsinny, being a smaller-sized species, also seems to benefit from the traditional minimum size limit management tool, which applies outside MPAs.

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## Introduction

Different species of wrasse (Labridae) are among the most numerous fish species on shallow rocky reefs and coastlines in Northern Europe, but their commercial value as food fish is low due to their relatively small body size. However, since the late 1980s, wild-caught goldsinny wrasse *Ctenolabrus rupestris* (Linnaeus, 1758), corkwing wrasse *Symphodus melops* (Linnaeus, 1758), ballan wrasse *Labrus bergylta* Ascanius, 1767 and rock cook *Centrolabrus exoletus* (Linnaeus, 1758) have been used as cleaner fish in open-pen farming of Atlantic salmon *Salmo salar* Linnaeus, 1758 to reduce infestations of salmon lice *Lepeophtheirus salmonis* Krøyer, 1837 in Norway and the British Isles (Bjordal 1988; Darwall et al. 1992; Treasurer 1996). The Norwegian demand for wild-caught wrasse increased sharply after 2009 when the lice problem intensified as the lice had evolved resistance to most of the available pesticides (Costello 2009; Besnier et al. 2014; Skiftesvik et al. 2014a). In 2014 and 2015, wrasse landings surpassed 20 million individuals, with corkwing and goldsinny wrasse being the dominant species (The Norwegian Directorate of Fisheries). Wrasse are caught by small boats operating inshore using fyke nets and pots and are transported with boats or trucks to the salmon farms. The fishery is regulated with minimum size limits, gear modifications for the escapement of undersized fish and a fishing closure from January to July. From 2015, minimum size limits were species-specific (goldsinny 11 cm, corkwing 12 cm and ballan 14 cm), after previously being the same for all wrasse (11 cm) (Skiftesvik et al. 2014a). In addition, a total landing cap of 18 million individuals has been set in 2016, divided among three regions (south, 4 million; west, 10 million; and north, 4 million individuals).

Whether and how the wrasse fishery affects the natural populations in Norway has not been investigated

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and the increasing exploitation has attracted concerns from the scientific community (Espeland et al. 2010; Skiftesvik et al. 2014a, 2014b; Halvorsen et al. 2016). The sedentary behaviour of wrasses poses a challenge for management and fisheries assessments; they hold territories and have small home ranges (Hilldén 1981; Potts 1985; Sayer 1999; Villegas-Ríos et al. 2013). Also, large differences in species composition, abundance and life-history traits have been observed on small spatial scales (Varian et al. 1996; Sayer et al. 1996a; Skiftesvik et al. 2014b). Goldsinny and corkwing populations are also genetically structured in Norway (Sundt & Jørstad 1998; Gonzalez et al. 2016). During the wrasse fisheries in the British Isles in the 1990s, harvested populations of corkwing and goldsinny showed signs of reductions in abundance and changes in size structure (Darwall et al. 1992; Varian et al. 1996; Sayer et al. 1996b). Probably around 150,000 wrasses were caught and used in Scotland in 1994 (Treasurer 1996), while the total catch in Norway in 2015 reached 21 million individuals. The higher intensity of the current Norwegian fishery raises concerns about its long-term sustainability. However, fishery impacts on the wild wrasse populations in Norway remain unclear, partly due to data deficiency.

Marine protected areas (MPAs) represent a tool for management and conservation where selected areas are partially or completely closed for harvesting. Depending on the MPA design (size, location, distance to nearby MPAs and fishing pressure) and the behaviour and ecology of the protected species, this may preserve natural densities and demography and in some cases increase fishery yields through spill-over of adults or increased overall recruitment (Babcock et al. 2010; Gaines et al. 2010; Goñi et al. 2010). MPAs have been highlighted specifically as useful for protecting and managing sedentary reef fishes (Roberts & Polunin 1991; Carr & Reed 1993; Gunderson et al. 2008). On the Skagerrak coastline in southern Norway, six smaller partially protected areas were established in 2006 (four) and 2012 (two), and have been demonstrated to yield positive effects on biomass, size structure and mortality rates of European lobster *Homarus gammarus* (Linnaeus, 1758) and Atlantic cod *Gadus morhua* Linnaeus, 1758 (Moland et al. 2013; Fernández-Chacón et al. 2015). These are partially protected areas where passive standing types of gear are prohibited (gillnets, pots and fyke nets). Wrasses are effectively fully protected in all these MPAs because they are not normally targeted in recreational hook-and-line fisheries.

Here, we studied catch per unit effort (CPUE), age, size and sex ratio of goldsinny and corkwing wrasse on the Skagerrak coastline, where harvested wrasse are exported to the salmon farming region in Western and Northern Norway (Taranger et al. 2013; Skiftesvik et al. 2014a). Coastal MPAs in the Skagerrak provide the opportunity to assess whether the increase in exploitation has affected important population parameters. Wrasse were sampled with passive gear in four of the MPAs and compared with corresponding control areas of a similar habitat, open to commercial fisheries. We predicted MPAs to have relatively higher CPUE and the wrasse to be older and larger than in the control areas. As males have been found to be the larger sex in both species (Dipper & Pullin 1979; Sayer et al. 1996a; Halvorsen et al. 2016), we also predicted the sex ratio to be more female-skewed in fished areas. A secondary objective was to compare the by-catch, size, age and sex composition of wrasse caught in fyke nets and baited pots, which are the two types of gear used in the commercial wrasse fishery and therefore potentially valuable for evaluating gear-based management regulations.

## Material and methods

### *Study area*

The four MPAs and control areas are situated on the Norwegian Skagerrak coast outside the towns of Arendal, Tvedestrand (two MPAs) and Risør (Table I, Figure 1). The coastline is characterized with many small islands and skerries with rocky and sandy bottom substrate. The two youngest MPAs (Tvedestrand) are larger than the older ones (Table I, Figure 1). The control areas were selected on the basis of habitat similarity to sites in the corresponding MPA (exposure, kelp coverage and rocky bottom substrate). MPA and control pairs were separated by a depth barrier (>20 m), or by having at least 900 m of coastline between them (Figure 1). The region under study (Aust-Agder county, southern Norway) has sustained a moderate wrasse fishery since the early 1990s. Gjøsæter (2002) reported that 15 fishermen operated within the county, catching typically 50–100,000 wrasse per year. Consulting with the current fishermen, the number of fishermen is

**Table I.** The location, size, year of establishment and exposure to open sea of the MPAs surveyed in this study.

| Locality | MPA location | MPA size ($km^2$) | MPA est. | Exposure |
|---|---|---|---|---|
| Flødevigen (F) | 58°24′–25′N, 8°43′–46′E | 1.1 | 2006 | Moderate |
| Tvedestrand Inner (TI) | 58°34′–36′N, 8°56′–9°0′E | 4.1 | 2012 | Low |
| Tvedestrand Outer (TO) | 58°35′–37′N, 9°4′–7′E | 5.3 | 2012 | High |
| Risør (R) | 58°42′–44′N, 9°13′–15′E | 0.6 | 2006 | Moderate |

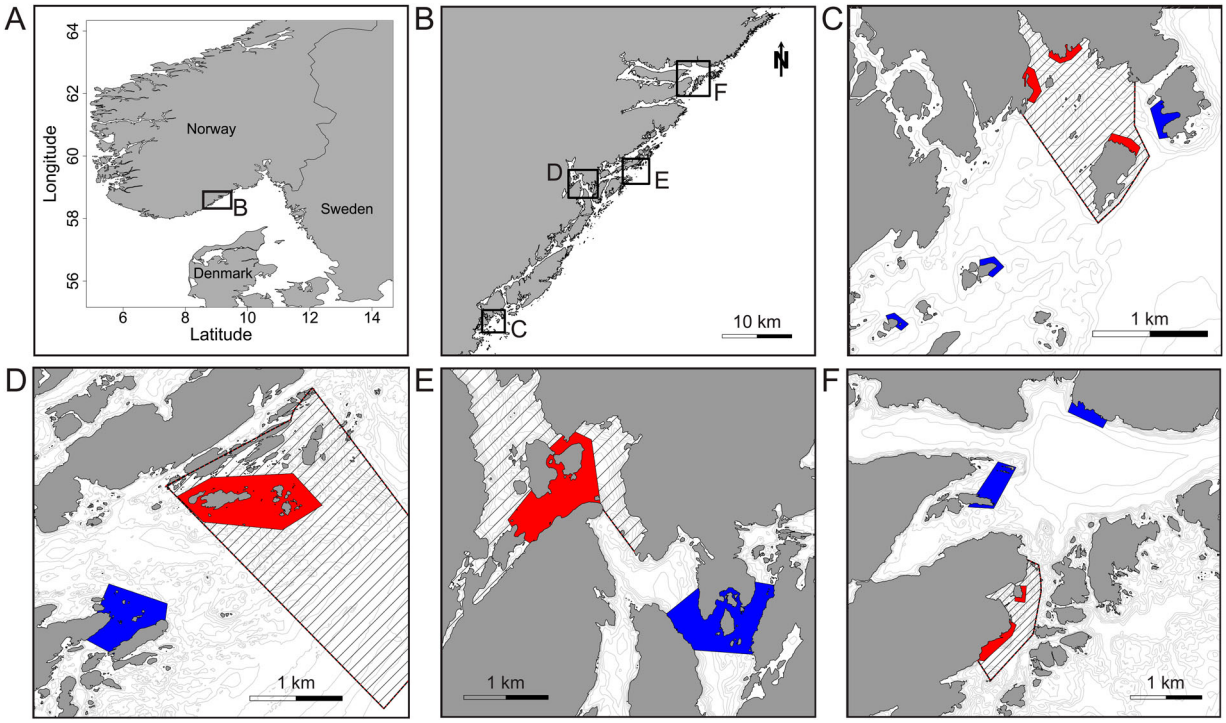


**Figure 1.** Map showing the study area in southern Norway (A) with the four localities along the Norwegian Skagerrak coast used in this study (B). (C)–(F) show the four MPAs (boxed areas with lines) with the sampling sites (solid fill). (C) Flødevigen, (D) Tvedestrand Outer, (E) Tvedestrand Inner and (F) Risør.

likely to have been slightly higher at the time of study. Detailed knowledge of previous fishing effort in the control areas was not available, but local wrasse fishermen confirmed that the control areas had been fished in the year of study (2013) or in earlier seasons. Seasonal catch data from the last three years was obtained from a fisherman operating near the Flødevigen MPA and control area. Wrasse fishermen in this region use small open boats and fish at all suitable inshore sites with rocky bottoms (<7 m depths) covered with *Laminaria* sp. and other macroalgae species (Gjøsæter 2002). Both pots and fyke nets are in use and several fishermen may operate within the same area.

### *Sampling*

Sampling was conducted from August to September 2013 (Table II). Wrasse were captured with unbaited fyke nets (5 m single leader, 55 cm diameter entrance ring and leader mesh size of 30 mm) and wrasse pots (rectangular prism-shaped, 70 × 40 × 29 cm, circular entrances (75 mm diameter), two chambers and 15 mm mesh-size) baited with 2–3 raw prawns *Pandalus borealis* Krøyer, 1838. As in the commercial fishery, the gear was deployed on rocky, kelp-covered substrates at 1–7 m depth and hauled the following day (19–26 hours soak time). At each site (MPA or control), goldsinny and corkwing wrasse were randomly collected for ageing and euthanized with an overdose of clove oil. An arbitrary minimum sample size of 50 individuals per site was decided upon. Sampling was conducted for 2–5 days, the duration depending on weather conditions and catch rate. Only the first goldsinny captured in each area ($n$ = 61–153) were collected for ageing because this species was more abundant than the corkwing. Goldsinny captured later were measured for total length and released onsite. All other fish species were identified, counted and released.

### *Ageing and sex determination*

The total length of the fish was measured to the nearest mm and sex was determined by examining external colouration and gonad morphology. Corkwing wrasse males are found in two distinct morphs, 'nesting males and sneaker males' (Uglem et al. 2000). Nesting males are readily distinguished from females and sneaker males by having distinct patterns of blue, green and red. The colouration of females and sneaker males is brown–green and they have a distinct blue urogenital papilla. Sneaker males and females are visually indistinguishable in the field, but could readily be sexed by inspecting their gonads. The female gonad

**Table II.** Number of gear used, number (*n*) of wrasse and goldsinny caught and aged (in parentheses) at the control and MPA sites.

| Locality (date) | Treatment | Pots | Fyke nets | % pots | *n* goldsinny (aged) | *n* corkwing (aged) |
|---|---|---|---|---|---|---|
| Flødevigen | MPA | 46 | 30 | 61 | 914 (153) | 90 (90) |
| (30.08–03.09) | Control | 47 | 31 | 60 | 1249 (146) | 112 (112) |
| Tvedestrand (inner) | MPA | 8 | 14 | 36 | 400 (97) | 80 (80) |
| (24.08–29.08) | Control | 15 | 24 | 38 | 328 (79) | 58 (54) |
| Tvedestrand (outer) | MPA | 6 | 6 | 50 | 195 (112) | 117 (117) |
| (24.08–29.08) | Control | 7 | 9 | 44 | 153 (98) | 86 (86) |
| Risør | MPA | 12 | 16 | 43 | 473 (100) | 108 (108) |
| (11.09–12.09) | Control | 12 | 18 | 40 | 194 (61) | 58 (58) |
| Total | MPA | 56 | 82 | 41 | 1982 (462) | 395 (395) |
| (24.08–12.09) | Control | 65 | 98 | 40 | 1924 (384) | 314 (310) |

Time of sampling during 2013 is also given for each locality (date format: dd.mm). See Figure 1 for details about the localities.

is pale or yellow and has clearly visible egg structures, whereas male gonads are opaque, thin and white. For goldsinny, the sexes are similar in appearance, but males have orange or red spots on the lower part of their abdomen behind the pectoral fins (Hilldén 1981). Sagittal otoliths were dissected out, cleaned and stored dry. For ageing, the otoliths were placed in black multi-celled trays containing 96% ethanol and photographed under a stereo microscope (20×; Leica MZ 16 A). The otoliths of both species have broad, opaque (summer) and narrow, translucent (winter) growth increments, which allowed age to be determined without further processing (Sayer et al. 1996a; Uglem et al. 2000). Age was determined by counting winter zones. Two trained people read the otoliths independently and agreed about the age of those yielding disparate estimates. Non-readable goldsinny otoliths were excluded ($n = 40$).

### *Data analysis*

Differences in body size (total length, TL) between sexes were assessed with two-sided *t*-tests assuming unequal variances. We used generalized linear models (GLMs) to test for differences between the sampling localities, effects of MPAs and influence of sampling gear on the following response variables: CPUE (the number of wrasse in each fyke net or pot haul), age, total length and sex ratio (proportion of males). The models were fitted separately for each species with the appropriate distribution of errors. A likelihood ratio test was used to compare the goodness of fit of models with and without an interaction effect between protection and locality for each response variable:

$$\text{response} = \text{Protection} + \text{Locality} + \text{Gear} + (\text{Protection} \times \text{Locality}) \quad (1)$$

$$\text{response} = \text{Protection} + \text{Locality} + \text{Gear} \quad (2)$$

This provided a framework for testing whether the responses to protection differed among the four localities. Including the Gear covariate accommodates for any variance arising from the differences in selective properties of the two gear types, as the proportion of the two gear types differed slightly (121 pots and 180 fyke nets in total; Table II). Because we compared models chosen a priori, all explanatory variables were kept in the final model (as determined by the likelihood ratio test) regardless of their statistical significance. CPUE was estimated for fish larger than or equal to the minimum size limit (110 mm for both species at the time of study, 2013), and modelled by a negative binomial error distribution using the MASS-package in R (Venables & Ripley 2002). The length data were modelled with a Gaussian error distribution with normality assumptions of the residuals checked by diagnostics plots from the fitted model object. For modelling age, the goldsinny data best conformed to a Poisson distribution, checked for over-dispersion by comparing degrees of freedom with residual variance of the model. For corkwing, 65% of the individuals were either one year old or young-of-the-year. Therefore, corkwing age was transformed to a binary response variable (age 0–1 = 0, age 2–4 = 1) before modelling. A binary response was also used to model sex ratio (the proportion of males). For corkwing, sneaker males were omitted from this analysis. Lastly, we compared the proportion of by-catch species in the two gear types with a proportion test. When reporting the observed relative difference in means between MPA and control areas, data from both gear types were pooled, as the relative proportions of the two gear types were similar in MPA–control pairs (Table II). All statistical analyses were performed using the R software version 3.2.2 (R Core Team 2015).

## Results

In total, 3906 goldsinny and 709 corkwing were captured and measured for total length for the eight study sites from 24 August to 12 September 2013; of

these, 846 goldsinny and 705 corkwing were aged (Table II). Mean length of goldsinny was 105 mm (range 56–164), while the mean length of corkwing was 140 mm (range 60–219). Thus, only 36.6% of the goldsinny were larger than the legal size limit at the time of the study (110 mm), compared to 93.2% for corkwing. Goldsinny mean age was 4.2 years and attained a maximum age of 15 years, while the average corkwing was 1.4 years, with only one individual reaching four years. Nesting males of corkwing were larger (mean = 150 mm) than females (mean = 137 mm; $t = 7.00$, df = 617.93, $P < 0.0001$) and sneaker males (mean = 127 mm, $t = 9.35$, df = 106.70, $P < 0.0001$), but no sex-related difference was evident for goldsinny ($t = -0.54011$, df = 1494.6, $P = 0.589$). Pooling all sampling sites, the goldsinny sex ratio was male-biased (62.7% males, SE = 1.7), while for corkwing, the sex ratio (nesting males to females) was slightly female-biased (47.2% nesting males, SE = 2.0). Nesting males were more common than sneaker males (79.3% of all males, SE = 2.1).

There were considerable differences in catch per unit effort (CPUE), length and age for both species between localities and MPA–control pairs (Figure 2). The CPUE of legal-sized goldsinny was significantly (33–65%) higher within MPAs relative to harvested control areas (Table III, Figure 3a). For corkwing, a model with locality × protection interaction effect was supported (Table III, Figure 3e). Three localities had higher abundance (61–91% observed difference in means) within MPAs (largest effect in the MPA in Inner Tvedestrand), whereas the Flødevigen MPA had 16.4% lower mean CPUE relative to the control area (Figure 3b). For length and age, the model with locality × protection interaction was supported for both species (Table III). All MPAs had relatively larger and older corkwing (Figure 3f,g), with a notably higher difference between the MPA and control area in Risør (age: 39%, length 16%). On the other hand, there was no clear effect of protection on goldsinny body size and age, where the model with interaction between locality and protection was supported (Table III). Goldsinny was smaller in the MPAs, with the exception of Flødevigen (Figure 3b). Goldsinny in Tvedestrand Inner MPA was 21% older than in the control area, while the differences in means between MPA and control areas were less than 3% at the other three localities (Figure 3c). The sex ratio in MPA and control areas did not differ for either species (goldsinny: $\chi^2 = 1.7827$, $P = 0.18$, corkwing $\chi^2 = 0.0076$, $P = 0.93$), but there were significant differences between localities for goldsinny, with more male-biased sex ratios in Risør (Table III, Figure 3d).

There were significant effects of sampling gear on CPUE for both species (Table III). For goldsinny, the observed mean CPUE was 32% higher in pots relative to fyke nets, whereas for corkwing, fyke nets had 72% higher relative mean observed CPUE. Moreover, pots caught smaller and younger goldsinny, but no differences were detected for corkwing (Table III). There were close to significant differences in sex ratio between fyke nets and pots, with pots capturing more males of both species (Table III). Other species than wrasse constituted 28% of the total catch in fyke nets compared to 15% in pots (Figure 4, proportion test $\chi^2 = 149.72$, $P < 0.0001$). Of specific interest was by-catch of the protected eel *Anguilla anguilla* (Linnaeus, 1758), which constituted 6% of the catch in fyke nets, but less than 0.1% in pots (Figure 4, proportion test $\chi^2 = 213.41$, $P < 0.0001$). Catch data from a fisher operating in the Flødevigen area show goldsinny to dominate the catch in all three years (Figure 5). Ballan and corkwing are captured in similar proportions, but with different seasonal trends, with catches of ballan highest in June and July, and highest in August and September for corkwing. A total of 47,101 goldsinny, 3992 corkwing and 6172 ballan wrasse were caught and sold by this fisherman in 2013.

## Discussion

This study applied a field-experimental approach to assess the effects of harvesting wrasse to be used as cleaner fish in salmonid aquaculture on wild wrasse populations. Using four replicated MPA–control areas, we found that targeted species tended to have higher catch per unit effort (CPUE) in MPAs. For the corkwing wrasse, MPAs had consistently larger and older fish, while these life-history effects for goldsinny were less clear. We also found that the two gear types can be selective on species composition and, for goldsinny, size and age. Admittedly, this study and its design have some limitations. Information on the intensity and distribution of the commercial fisheries would facilitate a clearer interpretation of the findings, but unfortunately this was not available. The fishermen did not have records of when and where they had been fishing and their reporting depended on the day-to-day weather conditions, season and competition from other fishermen in the same area. Moreover, the size, age and physical features of the MPAs varied, so in the strictest sense, the four MPA-control pairs are not true replicates. Nevertheless, the consistent MPA-effects evident for some of the measured parameters falls in line with our predictions

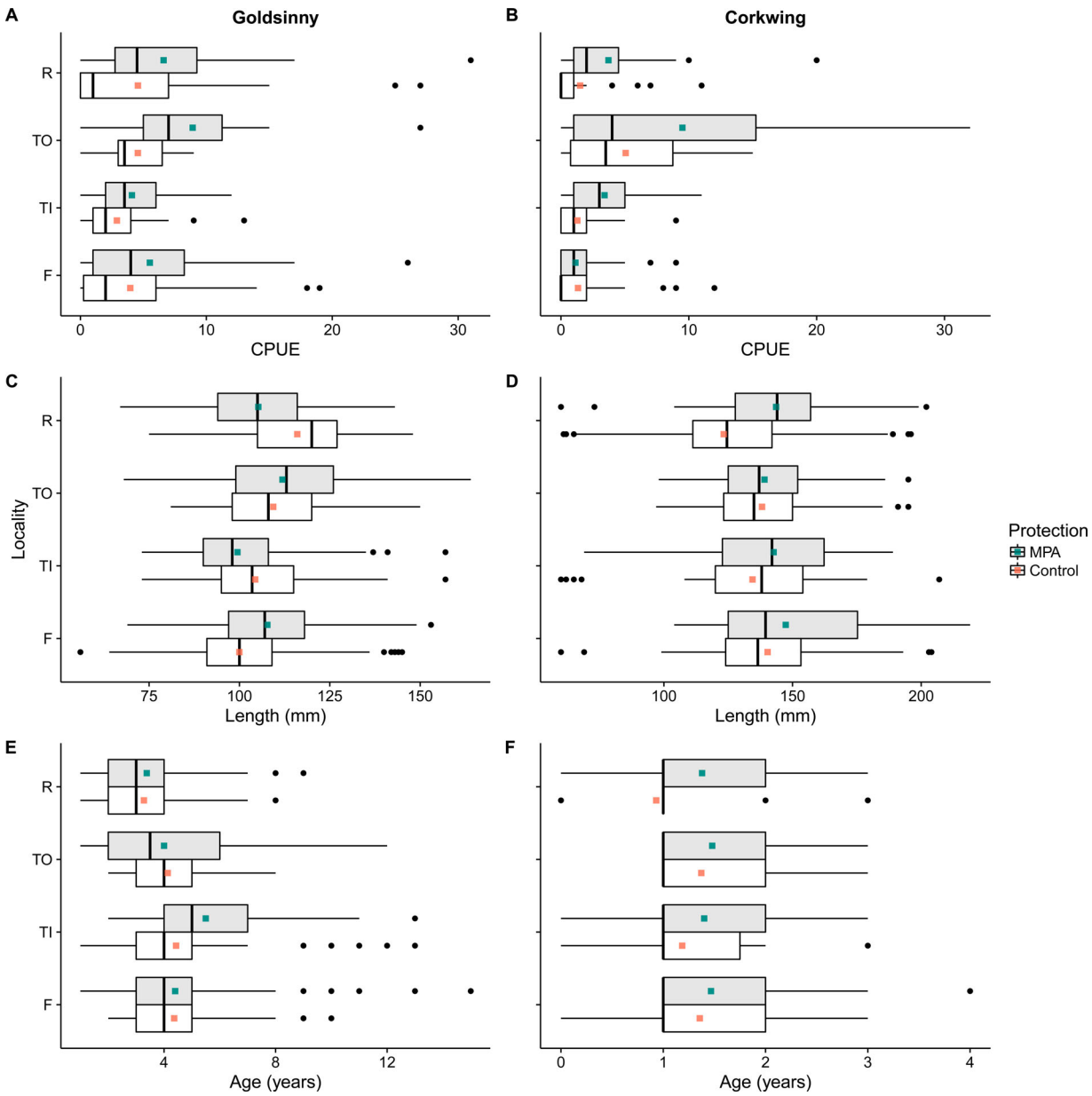


**Figure 2.** Boxplots showing the median (thick vertical line) and mean (solid squares) of catch per unit effort (CPUE: pooled for both gear types), total length (mm) and age of goldsinny and corkwing at the four sampling localities (F = Flødevigen, TI = Tvedestrand Inner, TO = Tvedestrand Outer and R = Risør). Shaded boxes are MPAs, open ones are control sites. The right and left edge of the box represents the 25th and 75th percentiles, respectively. The whiskers extend to the highest value maximum 1.5 times the distance between the 25th and 75th percentiles and filled dots represents outliers.

based on the development and intensity of the fishery in this region during the last 20 years. From a conservation perspective, this study adds to the growing amount of evidence of positive effects of MPAs on abundance and demographic structure of harvested fish species (Lester et al. 2009; Baskett & Barnett 2015). In particular, both goldsinny and corkwing wrasse are sedentary, territorial reef fish with limited adult dispersal capacity, so even small protected areas like those studied here should be efficient conservation tools (Gunderson et al. 2008; Wilson et al. 2010). Both species showed positive effects of MPAs on CPUE, although in Flødevigen, CPUE was slightly lower in the MPA. The abundance, mean body size and survival of coastal Atlantic cod, a potentially important wrasse predator, has increased substantially in the Flødevigen MPA after its implementation (Moland et al. 2013; Fernández-Chacón et al. 2015), so while fishing mortality may have declined, it is possible that this has been accompanied by an increase in natural mortality through increased predator densities (Babcock et al. 2010; Frank et al. 2011). The rate of such indirect

**Table III.** Summary of generalized linear models on the effects of protection (MPA vs. control), locality and gear on catch per unit effort (CPUE), total length, age and sex ratio (proportion males, sneaker males excluded for corkwing).

| Response | Species | Likelihood ratio test Protection × locality | Predictors | $\chi^2$ | Df | *P* |
|---|---|---|---|---|---|---|
| CPUE | Goldsinny | $\chi^2 = 1.30$, $P = 0.72$ | Protection | 8.66 | 1 | **0.003** |
| | | | Locality | 8.81 | 3 | **0.003** |
| | | | Gear | 7.08 | 1 | **0.008** |
| | Corkwing | $\chi^2 = 12.01$, $\boldsymbol{P = 0.007}$ | Protection | 6.18 | 1 | **0.013** |
| | | | Locality | 53.40 | 3 | **<0.0001** |
| | | | Gear | 19.10 | 1 | **<0.0001** |
| | | | Protection × Locality | 12.30 | 3 | **0.006** |
| Length | Goldsinny | $\chi^2 = 98.99$, $\boldsymbol{P < 0.0001}$ | Protection | 27.58 | 1 | **<0.0001** |
| | | | Locality | 100.19 | 3 | **<0.0001** |
| | | | Gear | 448.68 | 1 | **<0.0001** |
| | | | Protection × Locality | 100.03 | 3 | **<0.0001** |
| | Corkwing | $\chi^2 = 12.37$, $\boldsymbol{P = 0.006}$ | Protection | 18.00 | 1 | **<0.0001** |
| | | | Locality | 10.74 | 3 | **0.013** |
| | | | Gear | 0.03 | 1 | 0.85 |
| | | | Protection × Locality | 12.32 | 3 | **0.006** |
| Age | Goldsinny | $\chi^2 = 22.23$, $\boldsymbol{P < 0.0001}$ | Protection | 6.62 | 1 | **0.010** |
| | | | Locality | 56.69 | 3 | **<0.0001** |
| | | | Gear | 57.24 | 1 | **<0.0001** |
| | | | Protection × Locality | 22.23 | 3 | **<0.0001** |
| | Corkwing | $\chi^2 = 7.12$, $P = 0.07$ | Protection | 13.30 | 1 | **<0.001** |
| | | | Locality | 6.55 | 3 | 0.088 |
| | | | Gear | 0.55 | 1 | 0.46 |
| Sex | Goldsinny | $\chi^2 = 0.76$, $P = 0.86$ | Protection | 1.78 | 1 | 0.18 |
| | | | Locality | 20.08 | 3 | **0.0001** |
| | | | Gear | 3.30 | 1 | 0.069 |
| | Corkwing | $\chi^2 = 4.96$, $P = 0.18$ | Protection | 0.10 | 1 | 0.75 |
| | | | Locality | 5.93 | 3 | 0.12 |
| | | | Gear | 3.83 | 1 | 0.050 |

Significant *P*-values in bold. A likelihood ratio test was applied to select the model for statistical inference between models with and without protection × locality interaction effects.

effects has been shown to be slower than the direct effects of protection of target species (Babcock et al. 2010), which may explain the similar or better effect on CPUE in the two youngest MPAs in Tvedestrand. However, other factors could explain this as well, such as the larger size of the Tvedestrand MPAs, or it is possible that fishing intensity in the control areas has been higher there.

The MPA-effect on size and age differed between the two species; the MPAs had larger and older corkwing than control areas, but no clear pattern was evident for goldsinny. A possible explanation could be related to the finding of higher spatial variation between the different MPAs for goldsinny age and body size, so other local factors (e.g. density, predation and habitat) than fishing may have stronger effects on goldsinny life-history traits. For example, the observation that the CPUE of goldsinny was generally higher than that for corkwing could imply stronger density effects on the goldsinny. In that context, the reduced abundance of goldsinny we observed in control areas may have increased growth rates for the remaining fish. Moreover, as these two species have overlapping habitat requirements and diets (Costello 1991; Sayer et al. 1996a), a reduction in abundance of the larger corkwing wrasse could benefit the goldsinny. The considerable variation in goldsinny size and age structure over distances less than 30 km as found in this study implies a mismatch between the unit of management and the spatial variation in life histories, as seen on larger scales for corkwing (Halvorsen et al. 2016). The same minimum size regulations are enforced throughout Norway, and populations with faster growth would reach the size limit at a younger age and be more prone to overexploitation. If a size-selective fishery primarily targets immature fish, this may induce selection for earlier maturation, slower growth and increased reproductive investment at a younger age (Law 2000; Fenberg & Roy 2008; Heino et al. 2015). In a study conducted during the spawning season in 2014, corkwing examined in Flødevigen were found to mature in their first or second year, but few nesting males had reached maturation below the minimum size limit ($L_{50} = 139$ mm), while mature females were somewhat better protected ($L_{50} = 110$ mm) (Halvorsen et al. 2016). The maturation of goldsinny has not been investigated in Norway, but they have been found to mature in their second year in the British Isles (Darwall et al. 1992; Varian et al. 1996), and could spawn for two to three years before reaching harvestable size (10 cm in those studies) (Varian et al. 1996; Sayer et al. 1996b). In order to set

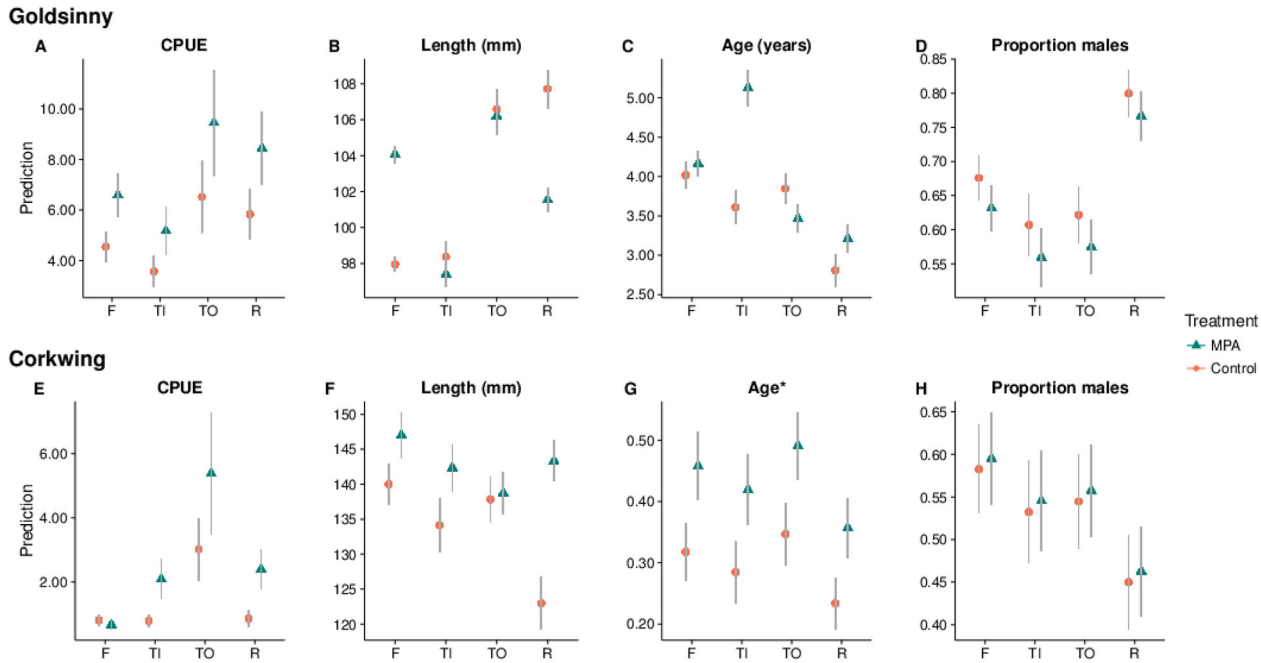


**Figure 3.** The predicted effect of protection (MPA or control site) on catch per unit effort (CPUE), body length, age and the proportion of males as estimated by generalized linear models for goldsinny and corkwing wrasse captured in pots at the four localities (F = Flødevigen, TI = Tvedestrand Inner, TO = Tvedestrand Outer and R = Risør). Error bars show standard error around the predicted means. *Corkwing age was modelled with a binominal age distribution (0: 0–1 and 1: 2–4 years).

appropriate size regulations for maintaining healthy breeding populations of goldsinny in Norwegian waters, a comprehensive spatial assessment of growth and maturation and the underlying factors causing variation should be conducted.

The sex ratio did not differ between MPAs and control areas for either species. This makes sense for goldsinny, as males and females were not found to differ in body size. Corkwing nesting males were larger than females, but because almost all corkwing wrasse were larger than the size limit at the time of study, the possibilities for the fisheries to be sex-selective were limited. Stronger male-biased size dimorphism has been demonstrated in populations further north on the western coast compared to those on the Skagerrak coast, with a consequently higher potential for sex-selective harvesting (Halvorsen et al. 2016).

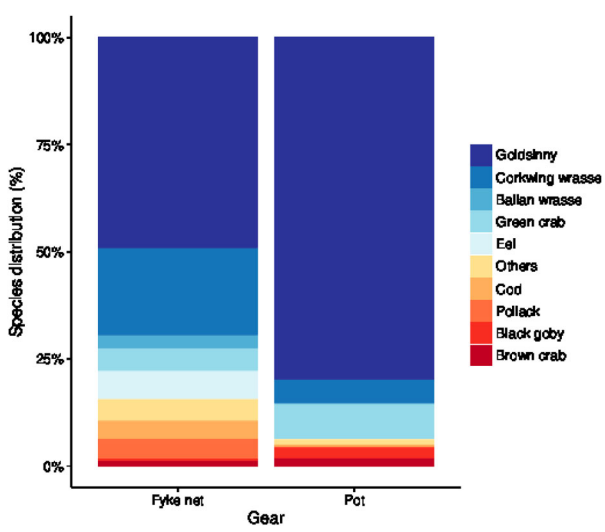


**Figure 4.** The relative species distribution in the two gear types used for sampling wrasse in Skagerrak 2013. The data are pooled for all sampling sites.

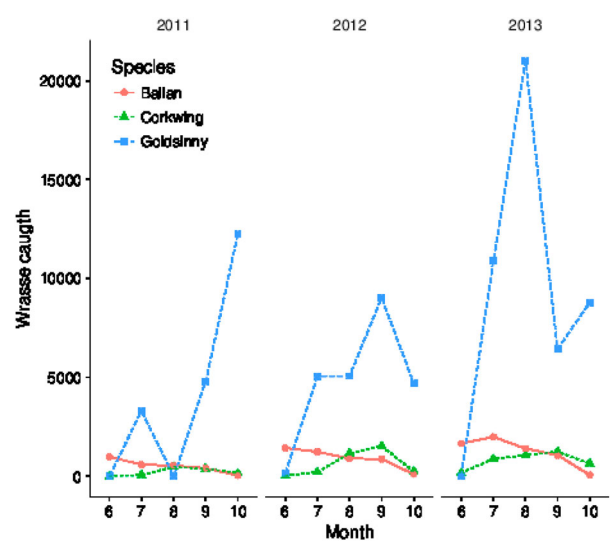


**Figure 5.** Seasonal variations in landings of the three target species of a fisherman operating in the Flødevigen area.

Currently, both pots and fyke nets are used in the fishery. Many of the wrasse fishermen in southern Norway were previously involved in a fyke-net fishery for eel, which was prohibited in 2010, with the eel now listed as vulnerable according to the International Union for Conservation of Nature (IUCN). A special permit has to be obtained in order to use fyke nets for fishing wrasse, and we have shown that fyke nets have a significantly higher proportion of eel and by-catch species. To our knowledge, fishermen release all by-catch at shallow depths, so the survival of by-catch species may be expected to be relatively high. Moreover, pots caught smaller and younger goldsinny, but this is expected, as the pots used had smaller mesh size than fyke nets. No gear differences in size and age were evident for corkwing, which is most likely related to their larger size and deeper body shape relative to goldsinny. The fisherman in Flødevigen had higher catches of ballan than corkwing, as opposed to what we observed in our sampling. However, the fisherman's catches of ballan were highest in June and July, whereas we sampled in late August and the beginning of September. In addition, ballan tend to prefer more exposed sites than do corkwing (Skiftesvik et al. 2014b), and three of the MPAs in this study were relatively sheltered, with low to moderate exposure.

Our study provides the first insights into the effects of harvesting wild wrasse in Norway, but it should be noted that the wrasse landings are considerably higher in western Norway than on the Skagerrak coastline (Espeland et al. 2010; The Norwegian Directorate of Fisheries). Salmonid aquaculture is virtually absent in Skagerrak, and harvested wrasse are transported to western and northern Norway, where the local wrasse population cannot sustain the demand for cleaner fish (Skiftesvik et al. 2014a). Thus, the modest but significant differences between MPA and control areas we found here would likely have been larger if a similar study was conducted in the more intensively fished areas but which unfortunately do not have MPAs. In addition, the annual national landings have increased by 32% since this study was conducted, so differences between fished and unexploited areas may have increased. The minimum size limit for corkwing was increased from 11 to 12 cm in 2015, but still 82% of the corkwing would be harvestable using the size distribution in our data. Reduction of wrasse densities may lead to cascade effects in the coastal ecosystems, where the different wrasse are important both as predators on molluscs and crustaceans (Sayer et al. 1995; Deady & Fives 1995a, 1995b) and as prey for larger species, such as gadoids, seabirds and otters (Steven 1933; Rui Beja 1995; Nedreaas et al. 2008). Moreover, the wrasse diet is size- and sex-dependent (Sayer et al. 1995; Deady & Fives 1995a, 1995b); thus, ecological consequences on prey species may be anticipated if fishing mortality is selective with regards to size and sex.

We have shown that MPAs in the Skagerrak have a higher abundance of wrasse and may sustain the natural size and age composition under increasing harvest pressure. Thus, MPAs appear to be a useful management and conservation measure for the targeted wrasses. By conserving a natural abundance, age and size structure, MPAs may have positive effects on recruitment and could act as a buffer for the eco-evolutionary effects of size-selective harvesting. Our data from the MPA–control pairs in the Skagerrak could provide a baseline for monitoring the development of the fisheries in this region, but we also suggest implementing networks of wrasse MPAs in the other harvested regions. There are still several knowledge gaps to be filled for the environmental consequences of using wild-caught wrasse as cleaner fish, specifically on the effect of selective harvesting on reproduction and recruitment (Darwall et al. 1992; Halvorsen et al. 2016), the indirect ecosystem effects and the consequences of the large-scale translocations and escapement of wrasse to genetically distinct populations further north in Norway (Sundt & Jørstad 1998; Skiftesvik et al. 2014a).

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## Disclosure statement

No potential conflict of interest was reported by the authors.

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