Distribution patterns and sexual segregation in chimaeras: implications for conservation and management

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Chimaeras such as *Chimaera monstrosa* and *Hydrolagus mirabilis* are commonly found in commercial bycatch of deep-sea fisheries in the Northeast Atlantic. Very little information exists on their life history, ecology or behaviour. Segregation of populations by sex and/or age classes has been demonstrated in several elasmobranchs, but whether segregation occurs in chimaeras, and if so what mechanisms are involved, remains unknown. This study investigates the distribution and sexual segregation of four species of chimaera (*C. monstrosa*, *H. mirabilis*, *C. opalescens n. sp.* and *Harriotta raleighana*) in relation to sex, size (maturity) class, bottom depth, and latitude. Data were obtained from annual trawl surveys undertaken by Marine Scotland, Aberdeen, from 1998–2009, at 400–2000 m in the Northeast Atlantic (55–59°N 5–11°W). A factorial General Linear Model (GLM) with planned contrasts indicated complex patterns of age- and sex-related segregation. All adult males and females were sexually segregated by depth: in all four species investigated females occurred at greater depths than males. Potential birthing grounds were identified for *H. mirabilis*. Latitudinal spatial segregation was not evident in relation to sex or maturity stage. The patterns of segregation reported here suggest a potential for differential exploitation of the sexes by spatially focused fisheries.

Keywords: chimaeras, depth, fisheries, marine protected area, sexual segregation.

Introduction

Chimaeras, also known as ratfish or ghostfish, are a group of species that form the subclass Holocephali within the family Chimaeridae. The life history and reproductive biology of deep-water chimaeras are poorly known (Sion *et al.,* 2004); very little information is available on their ecology and behaviour, primarily due to the depths at which they occur, a lack of targeted sampling and poor taxonomic resolution in historic data.

Recent interest in the exploitation of chimaeras, along with that of a number of squaliforme sharks for their meat and oil, has focused attention on the lack of biological information available for these species; this is particularly the case with regard to their life histories. Detailed understanding of life-history parameters is a necessity to the development of appropriate management strategies for such organisms. Such data may also enable us to determine which, if any, deep-water species could support sustainable commercial fisheries (Merrett and Haedrich, 1997; Calis *et al.,* 2005).

In the Northeast Atlantic, chimaeras are commonly caught as bycatch by deep-water (400–2000 m) fisheries, but due to their low commercial value they are usually discarded (Blasdale and Newton, 1998; Moura *et al.,* 2004). *Chimaera monstrosa* and *Hydrolagus mirabilis* are primarily caught as bycatch within the deep-water fishery in the Rockall Trough (ICES division VIa); *C. monstrosa* is the principle species discarded by the Westerly Gillnet Fishery for anglerfish (*Lophius piscatorius*) operating in this region, and accounts for 6–50% of the catch (DEFRA, 2007). This species has in the past been an exploratory target of spatially focused fisheries (DEFRA, 2007).

Depletion of species from deep-water environments may have long-term ecological implications, including consequences of reduced stock size and altered age-structure for population viability. Declining trends in abundance of many deep-water fish species as a result of fisheries exploitation and bycatch are well documented (Bailey *et al.,* 2009; Heymans *et al.,* 2010), what is not known,

however, is whether within-species depth segregation of the sexes exacerbates this as a consequence of differential exploitation. Currently, management of deep-water fisheries in the Northeast Atlantic takes little account of behavioural and life-history characteristics, such as sexual segregation, spatial and temporal movements and depth distributions, for deep-water chondrichthyans (Mucientes *et al.,* 2009).

Sexual segregation, the separation of members of a species such that the sexes live apart, either singly or in single-sex groups (Conradt, 1998) is a common behaviour and evident in many species of elasmobranchs (Clo *et al.,* 2002; Sims, 2003; Sims, 2005). As a behavioural pattern, it is likely to be influenced by both social and ecological factors such as temporal mating patterns, availability of prey, and population density (Sims, 2005). Depth and spatial segregation by size, sex and developmental stage are exhibited by many deep-water shark species (Girard and Du Buit, 1999), e.g. frilled sharks (*Chlamydoselachus anguineus)* (Tanaka *et al.,* 1990), rough skin dogfish (*Centroscymnus owstoni*) (Yano and Tanaka, 1988) and New Zealand lantern sharks (*Tempters baxter*), the latter exhibiting segregation by sex and/or age class (Sion *et al.,* 2004).

Adult males and females within a species use different habitats either within the same or different areas; habitats may be selected differentially by the sexes for social, thermal or forage-related reasons (Mucientes *et al.,* 2009). Anecdotal evidence suggests that chimaeras may segregate sexually in a similar way to other deep-water sharks, but whether segregation actually does occur in chimaeras, and if so what the underlying causes and mechanisms are, remains unknown.

Given the fisheries-related mortality of chimaeras (Calis *et al.,* 2005; DEFRA, 2007; Howell *et al.,* 2009), it is important for our understanding of the ecological consequences of population depletion to determine how these species are distributed, as well as whether they segregate sexually or by age within their depth ranges. No data are available with regard to their population numbers; however, they are K-selected species exhibiting extreme longevity, slow growth, low fecundity and late age at maturity (Gordon *et al.,* 1995; Koslow *et al.,* 2000). Patterns of exploitation and subsequent decline have been observed for many deep-water shark species (Gordon, 1999; ICES, 2008); it is therefore reasonable, based upon bycatch rates, to assume that chimaera populations are following similar patterns. Thus, there is a need to more fully understand their spatial and behavioural ecology. Determining sexual segregation in chimaeras has important management implications; different depth habitats for male and females gives the potential for differential fisheries exploitation of the sexes, identifying a possible need to manage stocks spatially to prevent further depletion and local extirpation.

This study examines depth-distribution patterns in chimaeras in the Northeast Atlantic, and in particular whether sexual and/or latitudinal segregation is evident; we also address the implications of our findings for conservation and management of these organisms. Four species were investigated, *C. monstrosa* Linnaeus, 2011, *Hydrolagus mirabilis* Collett, 1904, *Harriotta raleighana* Goode and Bean, 1895, and *Chimaera opalescens n. sp.* Luchetti, Iglesias and Stellos, 2011 (Luchetti *et al.,* 2011). We specifically tested the hypotheses that chimaera exhibit sexual segregation by mean depth and latitude in relation to maturity stage, sex, or a combination of both maturity stage and sex.

Methods

Surveys

Annual bottom trawls were undertaken by Marine Scotland, Aberdeen along the European continental slope in the Northeast Atlantic within ICES division VIa (Figure 1) during September from 1998–2009. Surveys were based on a stratified random sampling design using a Jackson BT184 rock hopper net comprising five meshes deep of 200-mm mesh (top panel), 5 meshes deep of 160-mm mesh (bottom panel), and 20-mm mesh in the cod-end. From 1998–2008, the rock hopper gear used 533-mm discs; in 2009 the discs were changed to 406-mm. Trawls were stratified according to depth and geographical criteria, with the use of ICES statistical squares 45E0, 44E0, 43E0 and 41E0. Trawl stations were present at 500, 1000, 1500 and 1800 m (full depth range 400–2000 m). All trawls were conducted at a speed of 3.5 knots, covering the area of $55-59°$N $5-11°$W, with near bottom depth and temperature recorded using a temperature and pressure sensor (Star Oddi Centi). The trawls were of different durations, with the majority lasting ~ 2 h. Preliminary investigation of trawl-length data revealed no correlation between depth trawled and trawl duration. Therefore the explicit probability of different maturity stages, sexes and species being caught was unbiased and, for the purposes of this study, trawl length was not standardized, allowing us to maximize information return from the available data.
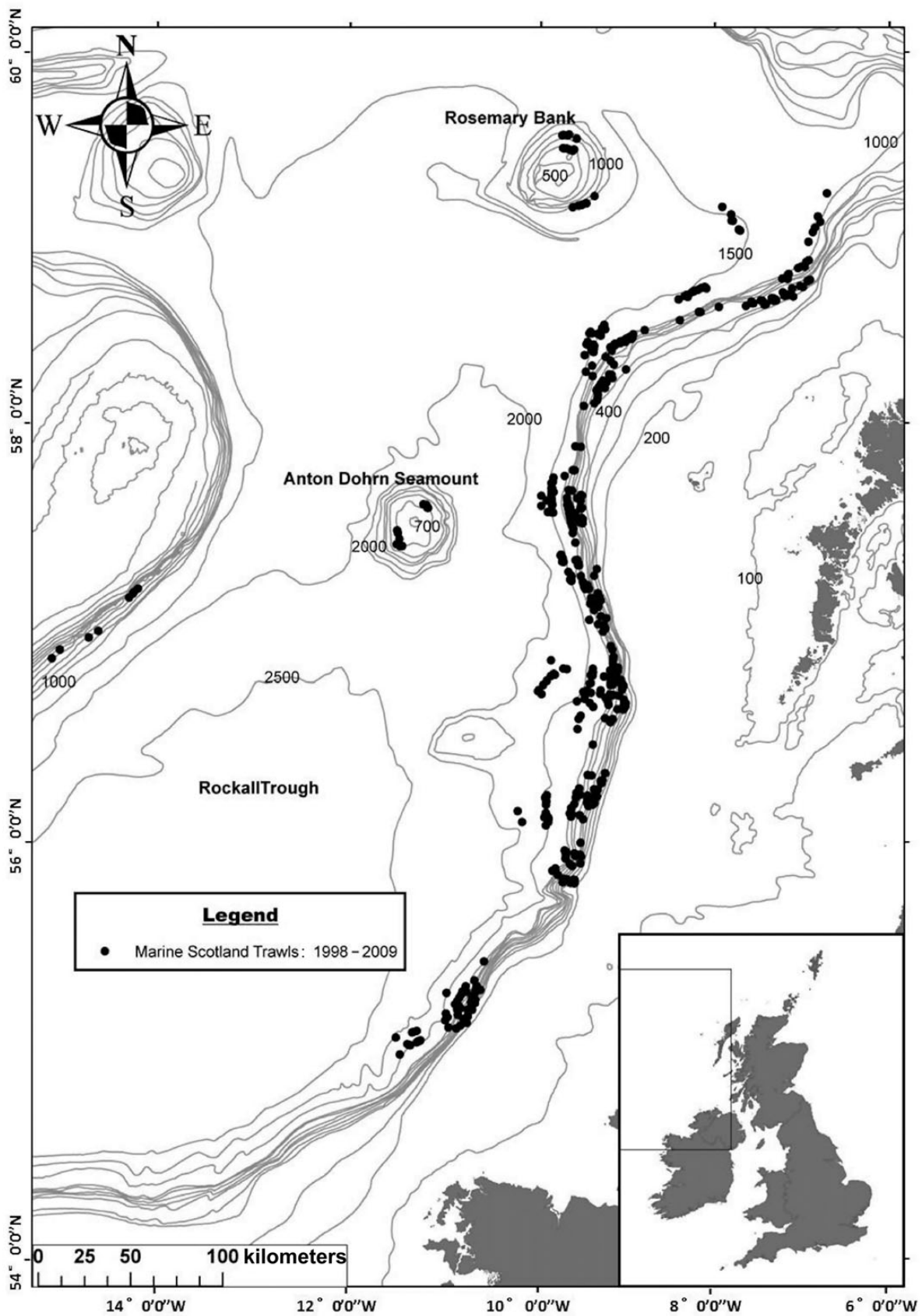
Individuals of study species captured (Table 1) were identified, sexed, staged, and the pre-supra-caudal fin length (PSCFL) (the length from the tip of the nose to the notch between the second dorsal and the caudal fin) recorded. A total of 305 trawls were conducted, each trawl returning a minimum of two individuals of at least one of the study species. A mean of 30 trawls per survey per year covered the entire known depth ranges for each of the species investigated [*C. monstrosa*: 400–1250 m (Gordon *et al.,* 1995), *C. opalescens*: 1000–1600 m (F. Neat, pers. comm.), *H. raleighana*: 650–2000 m, *H. mirabilis*: 600–1850 m (Mauchline and Gordon, 1983)].

Three maturity stage groups were defined for each species on the basis of published data (Table 2): (i) male and female juveniles (MJ & FJ), comprised of <1-year-old individuals; (ii) sub-adult males and females (MSA & FSA) comprised of immature individuals; (iii) adult males and females (MA & FA), defined as the PSCFL at first maturity. The PSCFL is assumed to be the same for both males and females (Calis *et al.,* 2005) for all species. *C. opalescens n. sp.* had been previously misidentified as *C. monstrosa* (F. C. Neat, pers. comm.); it was officially described in 2011. Accordingly, catch identifications for the entire data set (1998–2011) were revised prior to analysis in light of this taxonomic development. For the purposes of this study the maturity length groupings for *C. monstrosa* were used for this species.

Raw data were prepared for the purposes of data analysis; each individual captured was coded for maturity stage (Table 2) and sex. Data analysis to evaluate the effect of bottom depth was performed using raw data (i.e. not banded or aggregated by trawl).

Data analysis

All analyses were conducted using SPSS 17.0 (SPSS Inc. Chicago). To test the hypothesis that chimaeras segregate by maturity stage (juvenile, sub-adult and adult) regardless of sex, a Type III SS Univariate General Linear Model (GLM) was used, analysing the

Figure 1. Map of Marine Scotland (Formerly FRS) trawl locations 1998 – 2009. Bathymetric lines are in 100-m contours from 100 – 2500 m.

Table 1. Total number of males and females caught and pre-supra-caudal fin length (PSCFL) maturity groupings for each species.

Species name	No. of males caught	No. of females caught	Juveniles PSCFL (cm)	Sub-adults PSCFL (cm)	Adults PSCFL (cm)
C. monstrosa	12 174	9 224	<42	42–50	>50
C. opalescens	456	253	<42	42–50	>50
H. raleighana	740	505	<25	25–50	>51
H. mirabilis	781	513	<19	20–49	>50

Table 2. Results of 3 factorial GLM analysis with planned contrasts and Bonferroni corrections, dependent variable latitude, fixed factors, species, sex, and maturity stage.

Source	df	Std. Error	F	P
Species	3	0.008	52382	<0.001
Sex	1	0.011	0.137	0.711
Maturity stage	2	0.015	1587	0.800
Species*Sex	3	0.012	2415	0.065
Species*Maturity stage	6	0.015	0.652	0.065
Sex*Maturity stage	2	0.031	0.780	0.458
Species*Sex*Maturity stage	6	0.024	0.985	0.055

Table 3. Results of 3 factorial GLM analysis with planned contrasts and Bonferroni corrections, dependent variable bottom depth, fixed factors, species, sex, and maturity stage.

Source	df	Std. Error	F	P
Species	3	1.037	3006.71	<0.001
Sex	1	2.819	5.063	0.024
Maturity stage	2	1.958	9.271	0.001
Species*Sex	3	1.582	40.752	<0.001
Species*Maturity Stage	6	0.956	402.214	<0.001
Sex*Maturity stage	2	4.683	4.928	0.007
Species*Sex*Maturity Stage	6	4.916	16.942	<0.001

bottom depth of each individual sampled (dependent variable), with maturity stage and species as fixed factors. Data were routinely tested for non-homogeneity of variance prior to running GLMs, and inspection of unstandardized residuals was used to verify conformity to assumptions of the GLM: none of the datasets required transformation to achieve homogeneity variances. In these analyses, depth of occurrence was used as a summary surrogate for other physical parameters such as temperature and pressure. We found a strong correlation between temperature and depth in exploratory analyses but chose to analyse depth as a dependent variable since GLM models using depth had the highest overall R^2 values and lowest Akaike Information Criterion (AIC) scores, while retaining the same patterns of inference as analyses of temperature data.

To determine whether chimaeras segregate by mean depth either according to sex, maturity stage, or species (fixed factors), a factorial Type III SS GLM was used with planned contrasts using a Bonferroni correction based upon estimated marginal means to test for between-level comparisons within each factor combination. Furthermore, our data span a considerable latitude, therefore an additional factorial Type III SS GLM was conducted to determine whether chimaeras segregate by latitude either according to sex, maturity stage or species (all fixed factors).

One area of potential confounding in the data examined arises from patterns of autocorrelation and colinearity between depth and spatial proximity; locations close together in space are more than likely to be close in terms of depth, therefore spatial and bathymetric segregation may confound one another. With data spanning over a decade it is difficult to realistically divorce the effects of these two variables. However, it is nonetheless reasonable to hypothesize that in a large dataset such as ours, spatial or bathymetric segregation should manifest itself as autocorrelation within counts for the separate sexes, and that if autocorrelation is greater for bathymetry than for spatial separation, this signal is ecologically interpretable. We therefore divided the data into males and females for each species in each trawl, and calculated the sum of individuals in each category. We then conducted Mantel tests correlating a distance matrix based on numbers of fish, with separate matrices based on bottom depth and physical separation between the trawl locations calculated

from UTM x,y co-ordinates. The results of these tests indicated that bathymetric similarity is a better correlate of differences in fish numbers than is spatial proximity of the trawl sites.
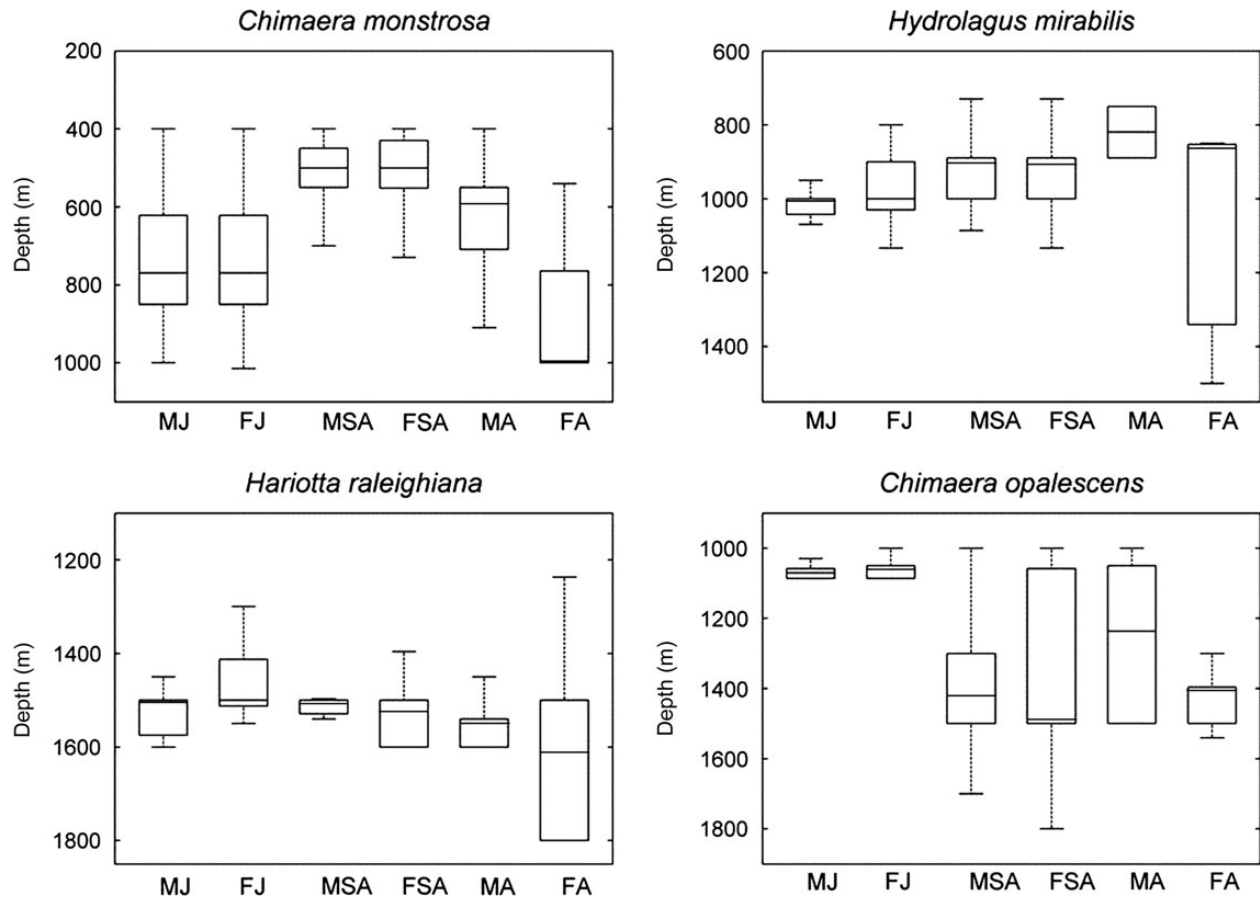
Results

The factorial GLM indicated latitudinal segregation by species. *C. monstrosa* and *H. mirabilis* were found in the southern part of the trawl range (55–56°N), whereas *H. raleighana* and *C. opalescens* were most common in the north (57–59°N). Latitudinal segregation was not evident by sex or maturity stage within any of the species investigated (Table 3).

The factorial GLM with planned contrasts indicated complex patterns of age- and sex-related segregation in chimaerids. Depth segregation of maturity stage regardless of sex was evident within all chimaeras investigated, the specifics of which, however, varied at the individual species level, as detailed below. Each species of chimaera exhibited slight differences in the sexual segregation present in response to depth, with no definitive pattern attributable to all species. As no generalization can be made for sexual segregation, results are presented for each species separately.

Chimaera monstrosa

Juveniles, sub-adults and adults were segregated in relation to mean depth ($F_{1,24622} = 21.641$, $p < 0.001$) [Juveniles & Sub-adults (95% CI: 216.0, 226.3), Juveniles & Adults (95% CI:52.6, 93.0), Sub-adults & Adults (95% CI: 128.8, 216.8)]. There was a degree of overlap in depth distribution between males and females as well as the maturity stages, though both adults and juveniles were more common in deep waters, while sub-adults were more common in shallow waters (Figure 2). Sexual segregation by depth (Table 4) was evident. Adult males were more common in shallower waters. A contradictory result was found in the adult females, whereby females were more common in deeper habitats (Figure 2), but upon further investigation, a secondary peak of adult females was found within shallower sites. Sexual segregation was not evident in the sub-adult maturity stage.

Figure 2. Depth distribution of males and females by maturity stage. (The central mark is the median, the edges of the box are the 25th and 75th percentiles, and the whiskers extend to the most extreme points not considered outliers). (MJ = Male Juvenile, FJ = Female Juvenile, MSA = Male Sub-Adult, FSA = Female Sub-Adult, MA = Male Adult, FA = Female Adult.)

Hydrolagus mirabilis

Juvenile and sub-adult maturity stages were segregated from adult maturity stages by mean depth ($F_{1.24622} = 0.190$, $p > 0.001$), [Juvenile & Adult (95% CI: 90.3, 173.3), Sub-adult & Adult (95% CI: 114.2, 147.4)]. There was a degree of overlap in depth distribution between males and females as well as in maturity stages, but juveniles were more common in deeper waters, while sub-adults were more common in shallower waters. Juvenile and sub-adult males and females were not segregated in relation to mean depth (Table 4); however, adult males and females were segregated $F_{1.24622} = 5.151$, $p > 0.05$ (Figure 2) (95% CI: 195.8, 439.0); adult females were more common in deeper waters, while adult males were more common in shallower waters.

Harriotta raleighana

Regardless of sex, juveniles were more common in shallower waters, while sub-adults and adults were more common in deeper waters (Figure 2). Sexual segregation was evident for both sub-adults and adults in relation to mean depth (Table 4); $F_{1,24622} = 60.286$, $p < 0.001$ [Male Sub-adult & Adult (95% CI: 14.8, 95.2), Female Sub-adult & Adult (95% CI: 13.8, 77.0)]; in both maturity stages, females were more common in deeper depths, whereas males were more common in shallower sites (Figure 2). There was a degree of overlap in depth distribution between males and females as well as the maturity stages for this species.

Chimaera opalescens

Juveniles and adults were segregated in relation to mean depth ($F_{2.24622} = 71.384$, $p > 0.001$) (95% CI: 232.7, 316.0); there was a degree of overlap in depth distribution between males and females as well as the maturity stages, though juveniles were more common in shallower waters, while sub-adults and adults were more common in deeper waters (Figure 2). Sexual segregation was evident for both sub-adults and adults in relation to depth (Table 4); in both maturity stages, females were more common in deeper waters, while males were more common in shallower sites (Figure 2).

Discussion

This study indicates complex patterns of age- and sex-related segregation; all species of chimaeras exhibited slight differences in the sexual segregation present in response to depth. Despite these taxonomic differences, this study provides evidence for maturity-stage segregation regardless of sex, and sexual segregation within maturity stage with depth to varying degrees dependent upon species.

Sexual segregation of adults

Sexual segregation by mean depth was evident across all four species investigated, with adult females occupying greater depth habitats compared to those of males. Segregation in this way has been

found in other deep-water species. The Portuguese dogfish (*Centroscymnus coelolepis*) and the roughskin dogfish (*Centroscymnus owstoni*) were shown to undergo sexual segregation by depth (Yano and Tanaka, 1988). For these species, catches significantly favoured males at shallower depths, with females occurring in deeper waters (Yano and Tanaka, 1988).

Sexual segregation with depth in adults may have arisen from social factors such as mate avoidance, segregation being maintained by aggression of one sex towards another (Main and Coblentz, 1996). Male chimaeras possess secondary sexual structures including a frontal tenaculum, a small club like structure with a bulbous tip armed with numerous sharp denticles located on the top of the head (Didier, 2004). This structure is unique to chimaerids and is assumed to play a role in mating. It has been suggested that males use this appendage to grasp the pectoral fin of the female during copulation (Didier, 2004). This biological characteristic may result in mate avoidance in mature females and therefore result in sexual segregation. Frequent mating may have a high cost for females due to blood loss or possible infection from bites or manipulations, evident within many shark species including the blue (*Pironace glauca*) and nurse sharks (*Ginglymostoma cirratum*) (Pratt and Carrier, 2001). Segregating away from the opposite sex when not engaged in mating activity may be the best behaviour for both breeding success and survival from repeated and prolonged mating attempts (Pratt and Carrier, 2001).

For all species adult males were observed within relatively shallower warmer waters. Initiation of spermatogenesis may be the underlying cause for males residing within shallower habitat, consistent with the behavioural bioenergetics hypothesis (Sims, 2003). Optimal external temperatures are known to be a determinant of both hormone production and steroid biosynthesis within testicular tissues; this has been noted in both the lesser spotted dogfish (*Scyliorchinus canicula*) and the spiny dogfish (Dobson and Dodd, 1976; Garnier *et al.,* 1999; McClusky, 2005). Residing within warmer waters may have a thermal effect upon the reproductive organs of chimaerid fishes.

For adult females there may be a trade-off in minimizing sexual conflict and maximizing reproductive output. *C. monstrosa* adult females exhibited a preference towards deeper (888 m) depths. However, upon further investigation, a large group of adult females were found to aggregate between 500 and 600 m, coinciding with the mean depth of adult male occurrence. It is possible that groups of females undertake migration to shallow waters to male groups in order to mate, returning to greater depths to support embryo growth (Klimley, 1987). In addition, at shallower depths, higher temperatures and increased prey availability may facilitate increased metabolic rate and therefore growth (Sims, 2005). For the scalloped hammerhead shark (*Sphyrna lewini*), sub-adult females move to offshore seamounts to feed on more energy-rich prey to support the growth and development of large, high-cost embryos (Klimley, 1987). Within spurdog populations (*Squalus acanthias*) in New Zealand waters, adult females move to spend the first year of pregnancy in shallow waters, and then migrate back in the second year to deeper waters (below 1400 m) where they reside for parturition (Girard and Du Buit, 1999).

Segregation of juveniles
The juvenile stages were not sexually segregated by depth for *C. opalescens*, *H. raleighana* or *H. mirabilis*, but were for *C. monstrosa*. However, within *C. monstrosa* juveniles, there was only a minor difference in mean depth of male and female occurrence of

17 m. It is likely that there is no sexual segregation of juveniles within chimaera species.

For each species investigated, juveniles segregated from the adult population. Where this type of segregation has been observed in other elasmobranch species it has been attributed to the predator avoidance hypothesis, whereby juveniles aggregate at shallower depths than adults to reduce the risk of cannibalism (Ebert, 2002). Similar patterns have been noted in deep-water squalid sharks, whereby segregation by depth and maturity stage was evident (Yano and Tanaka, 1988). However, chimaeras feed on benthic invertebrates, and their dentition is beak-like; having similar mouth morphology to that of rays, therefore, they do not possess the associated dentition to be cannibalistic (Dean, 1906; Mauchline and Gordon, 1983). Juvenile segregation from the adult populations may be related to avoidance of predation from other deep-water shark species, or to aggregation in areas where suitable prey occur. The diet of juvenile chimaeras differs from that of adult chimaeras (Mauchline and Gordon, 1983). The identification of favourable depths for juveniles within each species' depth range suggests these depths may serve as potential nursery grounds (Heupel *et al.,* 2007) for these species. Although adults and juveniles generally segregated within all species, the situation was slightly more complex as a result of adult sexual segregation. *H. mirabilis* adult females were found to occur at very similar depths to that of juveniles (∼1000 m) suggesting this depth may also serve as a possible birthing ground for this species.

Segregation of sub-adults
There was no consistent pattern across the chimaeras investigated. Sexual segregation in sub-adult maturity stages was found in *H. raleighana* and *C. opalescens*; however this was not the case in *C. monstrosa* and *H. mirabilis*. These inconsistent findings for sexual segregation may have arisen from a potential problem with use of length as an indicator of maturity stage, possibly resulting in sub-adults being classed as adults and vice versa.

For *H. mirabilis,* it was found that sub-adults and adults aggregated at a shallower depth to that of juveniles found in deeper waters. Concurrent findings have been observed for sub-adults of *Hydrolagus collei*, a New Zealand species of chimaera, found to aggregate in deeper waters while adult fish exhibit seasonal migrations to shallower habitats (Quinn *et al.,* 1980). Similar results were found for *C. opalescens* and *H. raleighana.* However, within these two species, the adults and sub-adults aggregated at a greater depth than the juveniles found in shallower waters. For *C. monstrosa*, sub-adults were segregated away from both the juveniles and adults, residing in shallower waters.

These results are contrary to those for some deep-sea shark species, whereby sub-adults are known to segregate away from the adults of the population to avoid the risk of cannibalism and depredation of sub-adults by mature individuals (Morrissey and Gruber, 1993; Heithaus, 2001; Robbins, 2007). However, as discussed previously, cannibalism is unlikely to occur within chimaera species, allowing for similar depth habitats to be occupied by both sub-adults and adults of *C. opalescens* and *H. raleighana.*

Unlike the Portuguese dogfish (*C. coelolepis*) that exhibits horizontal spatial segregation according to size and maturity stage (Verissimo *et al.,* 2011), none of the chimaera species investigated were spatially segregated by maturity stage or sex. It is likely that additional factors not analysed within this study are also responsible for the distribution of these species, such as benthic habitat type (substrate), water-mass structure and surface primary production

(Bailey *et al.*, 2009). These physical environmental factors relating to prey availability and predator–prey distributions may be important factors influencing segregation of chimaeras.

Conservation

Results suggest that all chimaera species investigated within this study exhibit maturity stage segregation regardless of sex, as well as sexual segregation by depth among adults. There is potential therefore for fisheries to differentially exploit the different sexes and maturity stages of important components of the population. The effects of differential exploitation of the sexes by fisheries remain poorly understood. However, evidence suggests human exploitation of sexually segregated sharks may lead to dramatic population declines (Clarke *et al.*, 2003), and there is no reason not to assume that the same may occur in the chimaera populations in the Northeast Atlantic.

Commercial fisheries reach depths of up to 1600 m in the Northeast Atlantic (Bailey *et al.*, 2009), however, the impacts of fishing on fish populations extend to the lower slope (2500 m) (Bailey *et al.*, 2009). Therefore, all of the chimaera species investigated here are vulnerable to exploitation from deep-water fisheries for the whole of their depth ranges. Intensive fishing practices in the area of study (ICES division area VIa) are highly likely to result in indirect selection of the sexes, affecting the viability of their populations. There is no requirement at present by fishing vessels to document sex information of sharks, rays and chimaeras captured (Mucientes *et al.*, 2009). Therefore fisheries exacerbating the decline of bycatch species such as chimaeras due to particular spatial and depth targeting, where one sex may predominate over another, is at present masked by a lack of data. This study indicates the need for spatial management of chimaerids, requiring the inclusion of areas where important components of the population remain, such as where juveniles reside as well as potential birthing grounds to ensure reproductive viability of the population and prevent localized depletion. It is also provides further evidence for the need for wide-scale, spatially referenced recording of the sexes by fisheries, as outlined by Mucientes *et al.* (2009).

The results of the study suggest the potential for identifying areas for chimaerid species where key components of the population reside. Potential nursery grounds have been identified for each species investigated (*C. monstrosa* 739 ± 1.76 m, *H. mirabilis* 1011 ± 8.13 m, *H. raleighana* 1467 ± 29.47 m, *C. opalescens* 1092 ± 8.90 m) as well as a potential birthing ground for *H. mirabilis* at 1011 m. If high fishing effort persists in these key areas, there is the potential for population decline (Clarke *et al.*, 2003). Fisheries have long used forms of spatial management, such as closure of nursery areas to protect sub-adult fish (Sainsbury and Sumaila, 2002). There is a growing awareness that marine protected areas (MPAs) have the potential to play an important role in elasmobranch conservation, especially for the protection of vulnerable critical habitats such as nursery and mating grounds (Baum *et al.*, 2003; Heupel and Simpfendorfer, 2005; Heupel *et al.*, 2007).

An important limitation of this study is that the sampling took place in September of each year, and at this stage there is no way to verify whether the sexual segregation and distribution patterns described here are the same throughout the year, or if seasonal changes occur. However, the presence of all maturity stages including mature females seems to indicate that both mating and parturition occurs during the late summer, or potentially all year round, as no clear egg-laying period has been defined for the species investigated.

It is now widely accepted that deep-water fish stocks cannot sustain high levels of exploitation and that different management systems are required (Clarke *et al.*, 2003). The use of MPAs as a fisheries management tool has been highlighted by a number of studies (Lauck *et al.*, 1998; Hilborn *et al.*, 2004; Hilborn, 2007). Selected "high risk" areas such as nursery grounds could be designated as MPAs or no-take zones, providing refuge for specimens during life stages when vulnerability to exploitation is particularly high. However, further work is needed to establish whether these areas are fixed or spatially and temporally dynamic.

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