Abundance Trends for *Hexanchus griseus*, Bluntnose Sixgill Shark, and *Hydrolagus colliei*, Spotted Ratfish, Counted at an Automated Underwater Observation Station in the Strait of Georgia, British Columbia

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Recordings from a time lapse video monitoring station on a shallow rocky reef in the Strait of Georgia, British Columbia, revealed a steep and continuous decline in the occurrence of *Hexanchus griseus* (Bluntnose Sixgill Shark) between 2001 and 2007, with relative abundance in 2006 and 2007 less than 1% of that in 2001. The relative abundance of another chondrichthyan, *Hydrolagus colliei* (Spotted Ratfish), decreased to 15% of 2004 levels in 2005 and 2006 and remained below 25% in 2007. There is no compelling explanation for these decreases. Over the past 25 years water temperatures have increased in the Strait of Georgia and there have been a number of El Niño warm water events, but diver observations of *H. griseus* at this site over the same time period give no indication of prior changes in abundance. Neither species is targeted by a fishery, but injuries, possibly related to hooking and entanglement, observed in 28% of individually identified *H. griseus* suggests this species may be taken locally as bycatch.

Key Words: *Hexanchus griseus*, Bluntnose Sixgill Shark, *Hydrolagus colliei,* Spotted Ratfish, automated underwater video, British Columbia.

Temporal changes in the relative abundance of non-commercial fish species may provide evidence of the effects of bycatch or of environmental perturbations that is obscured in data for commercial species because of their direct exploitation. However, standard removal-based methods of assessing relative abundance can be difficult, prohibitively expensive, and unacceptably destructive, particularly for non-commercial species which are uncommon or have low rates of growth and reproduction. Some non-destructive methods of quantifying local abundance, such as counts made by diver observers or extracted from diver collected video, are also labour intensive, and may contain unknown errors due to variation in observers, methods, or areas and times surveyed (Watson et al. 2005). An alternative non-destructive methodology is the use of video recording at strategically placed fixed automated observation stations (Dunbrack and Zielinski 2003). Analysis of such video records can provide cost effective, quantitative, and accurate count data that can be used to document site-specific seasonal and year-to-year changes in abundance, behavior, sex ratio, or size composition for several species simultaneously. Such a system has been in place since June 2001 on a rocky reef in the Strait of Georgia, British Columbia, Canada, primarily to monitor seasonal and year-to-year changes in the relative abundance of two chondrichthyan species: the Bluntnose Sixgill Shark, *Hexanchus griseus*, and the Spotted Ratfish, *Hydrolagus colliei* (Dunbrack and Zielinski 2003).

Hexanchus griseus has one of the most extensive geographic ranges among vertebrates (Compagno 1984), is one of the largest fishes (length to at least 5.5 m; Clark and Kristof 1990), and may have one of the longest vertebrate lifespans. Although little is known of its population biology, *H. griseus* is probably the highest trophic level predator throughout its range (Ebert 1994; Froese and Pauly 2007*), feeding on an array of large sized prey (Compagno 1984; Ebert 1986, 1994). The chimaerid *Hydrolagus colliei* is also a deep water demersal chondrichthyan but with a more limited distribution in the coastal NE Pacific from northern Mexico to Alaska (Hart 1973). The lack of direct exploitation, combined with the low reproductive rate and deep cold water habitat of these two chondrichthyans, suggests that temporal fluctuations in their abundance could be key indicators of perturbations in continental shelf ecosystems, including changes in thermal regime.

In British Columbia, both species are found in the deep waters of the Strait of Georgia and in deeper inlets of the adjoining mainland and the west coast of Vancouver Island (Hart 1973). Movements into shallow water are strongly seasonal and in the case of *Hexanchus griseus* uncommon (Dunbrack and Zielinski 2003, 2005). However, on a shallow rocky reef adjacent to Flora Islets in the Strait of Georgia, *H. griseus* has been sufficiently abundant from June to August that a valuable dive tourism industry based on encounters with these normally deep water sharks has existed since the 1970s (Harvey-Clark 1995). This unusual shallow water concentration of *H. griseus* prompted the establishment of an automated underwater observation station at Flora Islets that has provided largely continuous video records of the movements of *Hexanchus griseus* and *Hydrolagus colliei* along the base of the reef wall since June 2001. Initial analyses of these records documented marked seasonal changes in *Hexanchus griseus* activity at this site (Dunbrack and Zielinski 2003). This note describes year-to-year changes in the relative abundance of *Hexanchus griseus* and *Hydrolagus colliei* at Flora Islets between 2001 and 2007.

Materials and Methods

The Flora Islets study site is located in the Strait of Georgia off the SE tip of Hornby Island (49°30.9'N, 124°34.5'W). All observations were made using automated, fully submerged, time-lapse video recording (Dunbrack and Zielinski 2003). The time-lapse system consisted of a 12V black-and-white video camera (Sony model SPT-M320) and a time lapse video recorder (Sony Hi 8 EVO-250-NTSC with PGV-250 alarm recording adapter) in separate PVC housings. Between June 2001 and July 2002 the camera was on a tripod resting on the bottom, 3 m from the base of the reef wall, at a depth of approximately 40 m, and pointed along the downward sloping base of the wall. From July 2002 onward, the camera was fixed to the vertical reef wall, at a depth of 35 m, directly above the previous position, and facing downward. This vertical orientation allowed individual sharks to be identified based on dorsal scarring patterns and increased the visibility of *Hydrolagus colliei*, which were too cryptic in the horizontal view for reliable counting. The change in camera orientation did not alter the delectability of sharks inbound from deeper water, as the field of view for both orientations extended 10 m out from the base of the wall.

In time-lapse mode, video was recorded in sequences lasting 4/30 second at 8-second intervals, providing approximately 240 hours of continuous coverage with a normal 4-hour video tape. The maximum deployment time was adjusted by varying the daily "on time" with a programmable timer (e.g., 10-day deployment with a daily "on time" of 24 hours; 240-day deployment with a daily "on time" of one hour). Recording was not continuous throughout the study period because of technical difficulties, inclement weather that prevented tape and battery changes, and low light conditions associated with blooms of phytoplankton in the upper water layers. For further details of the time lapse video system see Dunbrack and Zielinski (2003).

To quantify relative abundance from the video records, a threshold visibility was defined based on the ability to distinguish a light colored target (approximately 250 cm^2) 10 m from the camera position. When this visibility threshold was exceeded all sharks and ratfish observed were recorded on video in at least two consecutive sequences (8 s apart) so that no fish should have been missed due to low visibility during count periods (visibility threshold exceeded). Counts were only made of sharks and ratfish inbound along the reef wall from deeper water and no attempt was made to identify individual fish. Counts may thus include repeat observations of the same individuals, but this should not affect the use of these counts as measures of relative abundance if fish behavior is independent of abundance.

Because of the strongly seasonal pattern of occurrence for both species, daily frequencies (fish/hour) were compared between years with data paired by calendar date. Analyses for *Hexanchus griseus* were based on day-by-day comparisons with the same date in 2001. To illustrate, for each date with recordings in 2002 and 2001, the frequency (sharks/hour) in 2002 was subtracted from the frequency in 2001 and the difference scored as positive, negative, or zero. Zeros were eliminated and a sign test was used to evaluate the null hypothesis of no difference in frequencies between years (Sokal and Rohlf 1995). This procedure was repeated for the years 2003-2007. Treatment of the ratfish data was identical, with the exception that comparisons were based on 2002, the first year *Hydrolagus colliei* was counted. To display the yearly data graphically, the frequency ratio (frequency on date i, year X)/(frequency on date i, 2001/2), was calculated for all dates with overlapping observations with 2001 (*Hexanchus griseus*) or 2002 (*Hydrolagus colliei*) and the mean ratios for each year plotted as a function of year.

Results

Sharks and ratfish were uncommon in September and October in all years and were virtually absent from the study site between November and May. Although both species were observed in June, there were extensive periods in this month when observations could not be made because of low illumination related to heavy phytoplankton blooms in the upper water column. Consequently, year by year comparisons of relative abundance were made for the months of July and August only.

The frequency of *Hexanchus griseus* was higher in 2001 than in any subsequent year and decreased continuously from 2001 onward, reaching a level of less than 1% of 2001 levels in 2006, with no sharks observed in 2007 (Figure 1). Frequencies in all years were significantly lower than in 2001 (Table 1). There was no significant change in the frequency of *Hydrolagus colliei* between 2002 and 2004, but frequency decreased significantly in 2005 to approximately 15% of 2002 levels and remained low in 2006 and 2007 (Figure 2; Table 2).

Discussion

Hexanchus griseus individuals at Flora Islets make only brief forays onto the reef from adjacent deep water (200-300 m), consequently the decrease in rel-

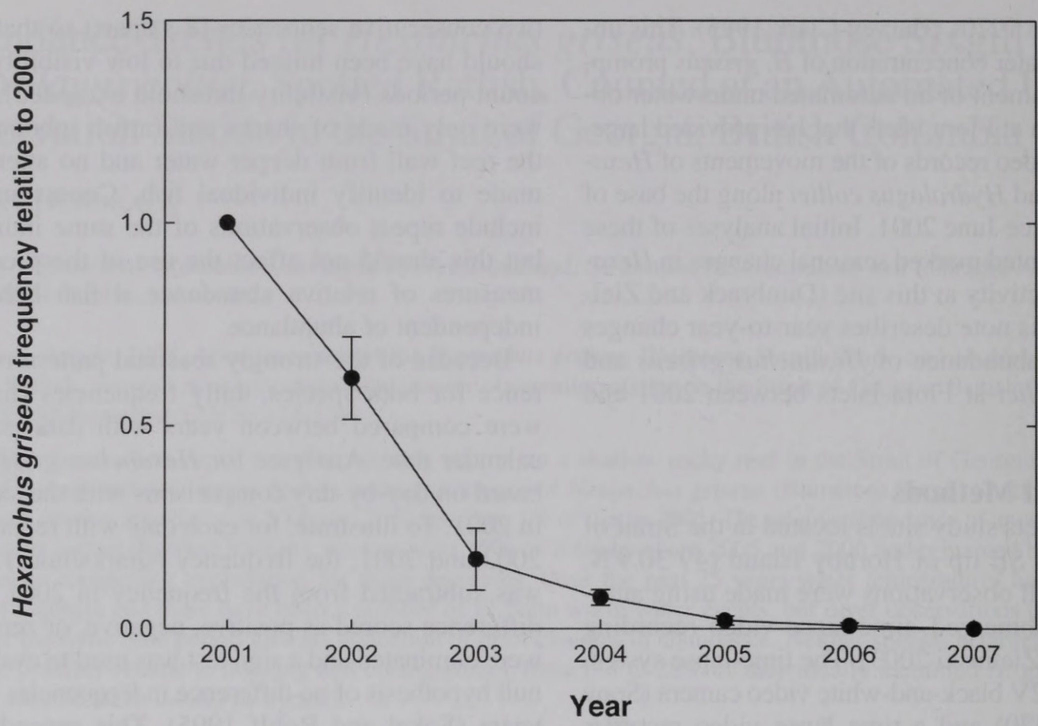

FIGURE 1. Mean frequency ratio for inbound *Hexanchus griseus* between 2002 and 2007 relative to 2001. The mean ratio for each year is the mean of the ratios calculated for each date with observational data in both the given year and 2001. Error bars represent standard errors. Lines connecting points are for illustration only and are not intended to indicate intermediate values.

ative abundance between 2001 and 2007 (Figure 1) may reflect similar changes in the local deep water population. This result is consistent with *H. griseus* sightings logged at this site by divers between 1979 and 2007. Only during the last five years do these logs show a downward trend, with diver sightings in 2005-7 being the lowest over the 25 years of observations (A. Heath and R. Zielinski, Hornby Island Diving, Hornby Island, British Columbia, unpublished data).

The cause of this apparent change in relative abundance, and its geographic scale, is unclear. Water temperatures, which can have a significant effect on habitat quality for fishes (Helfman et al. 1999), vary seasonally between 8° and 10°C in the deeper parts of the Strait of Georgia, but began a slow increase in the last decades of the 20th century and are currently about 1° warmer that in 1970 (D. Masson, Institute of Ocean Sciences, Sydney, British Columbia, personal communication). However, diver logs do not indicate a corresponding decrease in sightings between 1979 and 2000, nor during warm water anomalies associated with four El Niño events between 1980 and 2000. A decrease in abundance of *H. griseus* has also been noted anecdotally for a nearby site in Barkley Sound on the west coast of Vancouver Island. Here, sixgill sharks were regularly seen by divers during the 1980s and early 1990s, but sightings became rare after 1997 (N. McDaniel, Subsea Enterprises, Vancouver, British Columbia, personal communication; P. Mieras, Rendezvous Diving, Port Alberni, British Columbia, personal communication; R Dunbrack, unpublished observation). The effect of a commercial fishery for *H. griseus* in this area between 1991 and 1993 (Harvey-Clark 1995) is unclear.

TABLE 1. Sign tests of year to year comparisons of *Hexanchus griseus* frequency with July and August 2001. The sample size, *n*, is the number of overlapping days with at least one hour of observations and does not include ties. The positive score is the number of days on which frequency in 2001 exceeded that on the same date in the given year. *P* values are for two-tailed tests.

Year	2002	2003	2004	2005	2006	2007
	$n = 46$	$n = 18$	$n = 43$	$n = 48$	$n = 48$	$n = 40$
	+ = 36	+ = 17	+ = 43	+ = 48	+ = 48	+ = 40
	- = 10	- = 1	- = 0	- = 0	- = 0	- = 0
	ties = 1	ties = 0	ties = 0	ties = 0	ties = 0	ties = 1
	$P<0.0002$	$P<0.0002$	$P<0.0001$	$P<0.0001$	$P<0.0001$	$P<0.0001$

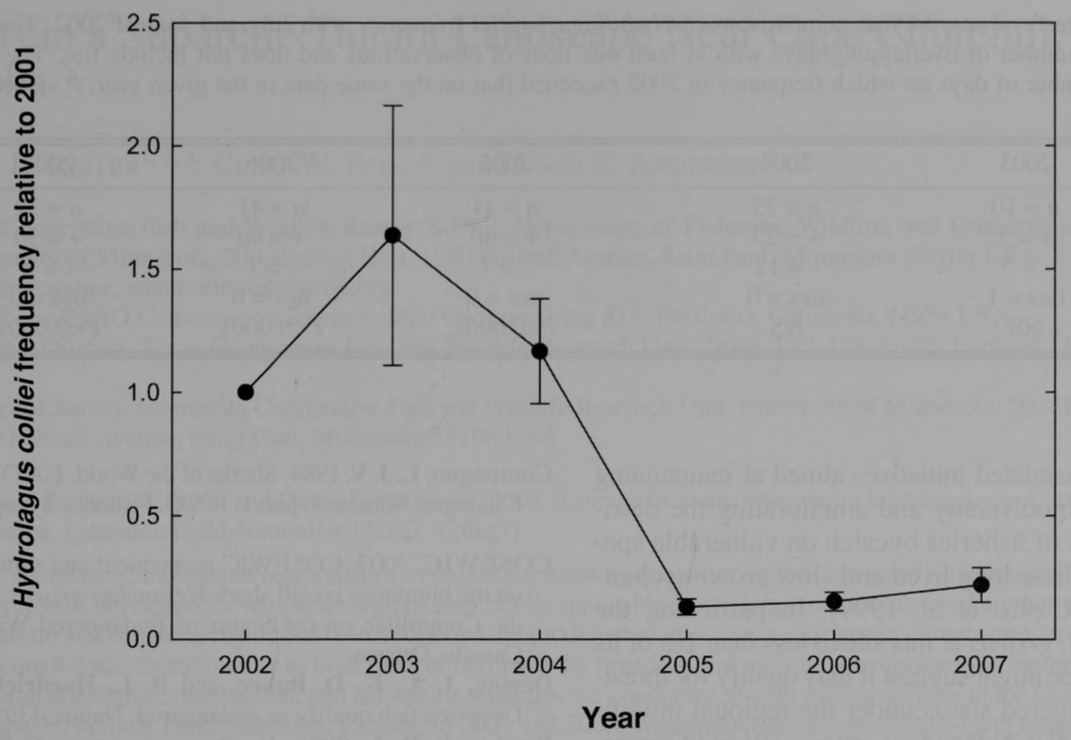

FIGURE 2. Mean frequency ratio for inbound *Hydrolagus colliei* between 2003 and 2007 relative to 2002. The mean ratio for each year is the mean of the ratios calculated for each date with observational data in both the given year and 2002. Error bars represent standard errors. Lines connecting points are for illustration only and are not intended to indicate intermediate values.

It is likely that the decrease in abundance of *Hydrolagus colliei* at Flora Islets also reflects a similar decrease in the local deep water population, but there are no historical observational data available for this species for comparison with the decline from 2004 to 2005/2006/2007. It is unknown how changes in the thermal regime of the Strait of Georgia might effect *H. colliei* populations.

There is currently no fishery for either species in the Strait of Georgia, but both are taken locally in gear set for dogfish (COSEWIC 2007). Although the extent of this bycatch is not well documented (COSEWIC 2007), there is evidence of an unusually large bycatch of *Hexanchus griseus* in the Strait of Georgia in 2002 (COSEWIC 2007). There is also visual evidence of detrimental effects of commercial fishing gear on individuals observed at Flora Islets. Overhead, close range video taken at Flora Islets in 2001 and 2002 showed that 10 of 35 individually identified *H. griseus* had wounds consistent with hooking and entanglement (Dunbrack and Zielinski 2005; Dunbrack 2006), a figure that probably underestimates injury frequency because overhead observations were confined to either a shark's right or left hand dorsal side; the jaw region, where most hooking injuries are observed by divers, was not visible. Injuries to *Hydrolagus colliei* individuals would not be detectable because of the fish's small image size on the video records.

The life histories of these two species in the north eastern Pacific are poorly understood but there is evidence suggesting habitat separation between adult and juvenile *Hexanchus griseus*. Stereo video length measurements of 35 individuals observed at Flora Islets ranged from 135 cm to 353 cm, all below the length at maturity for *H. griseus* (Dunbrack and Zielinski 2005; Dunbrack 2006). In addition, the collection, in the Strait of Georgia, of neonates, as well as a single female with near term embryos, suggests that these deep inshore waters are used for birth and juvenile rearing, but that mating occurs offshore (Dunbrack and Zielinski 2005). There is no information on the population biology of adults in offshore waters. However, even small increases in yearly adult mortality in a long lived species such as *H griseus,* possibly due to the same anthropogenic factors responsible for recent declines in most large marine fishes (Myers and Worm 2003), would eventually be expressed in decreased abundance of juveniles inshore.

The observations reported here demonstrate that low cost, continuous, non-destructive, video monitoring of the marine environment in key habitats can provide evidence of changes in the abundance of uncommon species that would otherwise go unnoticed. These are the first quantitative multi-year abundance data for either species; consequently, the downward trends at Flora Islets cannot be viewed in the context of longer term, or geographically more extensive, data. Nonetheless, such decreases call for further investigation as they may provide early evidence of more widespread perturbations in the marine environment and may invoke

TABLE 2. Sign tests of year to year comparisons of *Hydrolagus colliei* frequency with July and August 2002. The sample size, *n*, is the number of overlapping days with at least one hour of observations and does not include ties. The positive score is the number of days on which frequency in 2002 exceeded that on the same date in the given year. *P* values are for two-tailed tests.

Year	2003	2004	2005	2006	2007
	$n = 10$	$n = 35$	$n = 41$	$n = 41$	$n = 32$
	+ = 5	+ = 23	+ = 40	+ = 40	+ = 30
	- = 5	- = 12	- = 1	- = 1	- = 2
	ties = 1	ties = 0	ties = 0	ties = 0	ties = 0
	NS	NS	P<0.0001	P<0.0001	P<0.0001

government mandated initiatives aimed at maintaining local marine biodiversity and ameliorating the detrimental effects of fisheries bycatch on vulnerable species, such as these long lived and slow growing chondrichthyans (Castro et al. 1999). In particular, the reduction of *H. griseus* at this site to less than 1% of its 2001 abundance might suggest it may qualify for threatened or endangered status under the regional modifications of the IUCN Red List criteria (World Conservation Union 2001*; Gardenfores et al. 2001) adopted by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2005*), an approach suggested for other deep water demersal species that have undergone similar regional declines (Devine et al. 2006).

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