Intertidal Weir Study
Final Report

Temporal Patterns in Minas Basin Intertidal Weir Fish Catches and Presence of Harbour Porpoise during April - August 2013

Prepared for FORCE

by

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EXECUTIVE SUMMARY

The Bay of Fundy is recognized as an area of high ecological importance and is home to a diverse fish assemblage, including commercially and recreationally significant fishes, and many other marine species. The Fundy Ocean Research Centre for Energy (FORCE), a leading test center for tidal energy research and development, is currently assessing the potential for tidal energy development in the Bay of Fundy's Minas Passage. Since 2009, FORCE's Environmental Effects Monitoring (EEM) program has utilized a variety of strategies to gain a better understanding of fish presence and activity within and near the turbine test area. This project examines the use of commercial intertidal weirs along the shores of Minas Basin to address identified information gaps within the EEM program, in particular the seasonal abundance and presence of fishes that occur in Minas Basin and Minas Passage. The purpose of this investigation was to examine the temporal and environmental (e.g. temp, tide height) patterns in the presence and abundance of resident and migratory fishes, as observed in the fish catches at two Minas Basin intertidal weirs during April – August 2013. Sampling was conducted near weekly during daytime low tides from weirs in Bramber, NS and Five Islands, NS. Diel patterns were examined during two one-week periods during late July and early August at the Bramber site. Weir catches included 24 fish species at Bramber and 22 species at Five Islands. Pelagic fishes, especially those of the Clupeidae family, dominated the catches at both weirs. Abundance and species richness varied seasonally, and reflected the movement and spawning patterns of migratory fishes. Day/night sampling was conducted on 14 consecutive low tides during 12-19 July at Bramber. Considerable variation in abundance was observed, with greater fish captures during low tides at dusk/night. Harbour porpoise presence near intertidal weirs was low during summer, especially on the north shore; their absence may reflect their preference for deeper and cooler waters. Overall, the study showed that intertidal weirs are useful sampling platforms for assessing general patterns in the presence and abundance of fishes in Minas Basin and can strengthen on-going environmental monitoring near tidal energy development sites. Monitoring of an intertidal weir located within Minas Passage would better identify seasonal patterns in the movement of fishes closer to the FORCE test site.

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TEMPORAL PATTERNS IN MINAS BASIN INTERTIDAL WEIR FISH CATCHES

INTRODUCTION

The Bay of Fundy, bordered by Nova Scotia on the east and New Brunswick and Maine on the west, is regarded as the area in the Western Hemisphere with the greatest potential to harness tidal power on a commercial scale. Minas Basin, an embayment of the upper Bay of Fundy, experiences the world's largest tidal range, at times exceeding 16 m (Dyer et al., 2005). Tidal currents flowing into Minas Basin through the Minas Passage can reach 6 m/s at the surface on a spring tide (Oceans Ltd., 2009).

The Minas Passage is home to the Fundy Ocean Research Centre for Energy (FORCE), Canada's leading test center for Tidal In-Stream Energy Conversion (TISEC) devices and cable technologies. FORCE is currently assessing the potential for TISEC devices to operate within its test area, which consists of four berths and associated subsea cables and land-based infrastructure. Minas Passage, a 5-6 km wide body of water connecting Minas Channel to Minas Basin, is a highly energetic, hypertidal system characterized by large tidal amplitudes (up to 13 m tidal range on spring tides) and vast mudflats that are exposed at low tide. During a spring flood tide, up to 14 billion tonnes of seawater pass through Minas Passage into Minas Basin (http://fundyforce.ca/). This highly dynamic and productive system represents an ecologically significant environment for fish assemblages, including both migratory and resident marine species (Dadswell and Rulifson, 1994).

FORCE's Environmental Effects Monitoring (EEM) program has utilized a variety of strategies to understand fish use of the Minas Passage. Since 2009 these strategies have included the use of mid-water trawling vessels, hydroacoustic sonar surveys, and acoustic telemetry tracking studies. Trawling surveys conducted in 2010 showed lower than anticipated fish catches based on concurrent sonar detections. This suggested that the effectiveness of mid-water trawling in high flow waters is limited. Vessel-based hydroacoustic sonar surveys over 12-24 hr deployments have been useful for identifying fish biomass within Minas Passage; however, this survey method is expensive, collects data for limited time periods, and does not normally allow the species comprising the observed biomass to be identified.

Fish species occurring in the Minas Basin are well known from a range of studies conducted during the 1980s and 1990s (see review in Dadswell, 2010). Recent studies of fish and/or fish movements in Minas Basin and Minas Passage have been species-specific, and have focused on species either listed in the Canadian Species at Risk Act (SARA) or recommended by the Committee on Endangered Wildlife in Canada (COSEWIC) (Dadswell, 2006; Rulifson et al., 2008; Wehrell et al., 2008). Few directed fish studies have taken place within Minas Passage, with the exception of Bradford & Iles (1992), Stokesbury et al. (2012) and Redden et al. (2014). Prior to 2013, the Environmental Effects (EEM) Program at FORCE lacked an assessment of seasonal patterns in the presence and abundance of resident and migratory fishes in Minas Passage and adjacent waters.

It has been proposed that development of a comprehensive pre-turbine deployment baseline dataset be established regarding the fish assemblage in the immediate FORCE test area and outside the pilot area (DFO, 2012). Intertidal weirs in the vicinity of the FORCE test site were identified as potential monitoring platforms from which baseline data on the abundance and sizes of commercial and non-commercial fish species can be gathered (DFO, 2012). For centuries intertidal weirs have been a prominent method of fishing along the shores of the upper Bay of Fundy (Gordon, 1993) but only a small number are currently active. Weirs offer a low risk, low cost alternative to the use of trawling vessels and hydroacoustic instruments, and local weirs are operational for up to 5 months between April and September. This intertidal weir was initiated to provide useful baseline information on habitat use, and can be used in designing a long-term environmental effects monitoring program for commercial-scale tidal energy development in the Minas Passage.

Purpose

The purpose of the study was to examine fish catches in intertidal weirs in Minas Basin as a possible analogue for patterns in the abundance of fishes that travel though the Minas Passage and FORCE test area to spawning rivers or to feed in Minas Basin during the spring and summer months. Fish data of interest include species identification, size, and approximate abundance in weir catches during April to September 2013. Weir catch data can be used to examine temporal patterns in the presence and abundance of resident and migratory fishes. This study contributes to baseline studies for FORCE and helps to address gaps in the EEM program outlined by DFO's 2012 Science Response Review (DFO, 2012). The report indicated a lack of fish monitoring in the vicinity of the FORCE test site and in Minas Basin.

The main objectives of the weir study were:

1. To determine the temporal patterns in fish presence and abundance within intertidal weir catches at selected weirs on the north and south shores of the Minas Basin;
2. To describe the observed relationships between fish abundance in weir catches and relevant environmental factors, including water temperature, depth of the water column or high tide height, and the presence of predators, specifically harbour porpoise.

Main Fish Taxa

Dadswell (2010) reports that 77 fish species are known to be present within the Minas Basin, Minas Passage or Minas Channel. Due to a variety of factors, including fish size, fish behaviour, habitat selection and water temperature, not all of these species were expected to be present in weir catches over the duration of the study. Twelve species (described below) were regarded as common fish taxa, and were expected to be present in intertidal weir catches.

Alewife*, Alosa pseudoharengus (Wilson, 1811)*

Alewife is an anadromous pelagic species that lives most of its adult life at sea, entering fresh waters to spawn. Adult Alewife can be found in Minas Basin between March and September, with juveniles present year-round (DFO, 2007). Alewife spawning migrations normally begin in April or early May, peak in late May or early June and are completed by late June or early July. Growth to sexual maturity takes 4-5 years at sea; stocks migrate north and south annually along the Atlantic coast (Neves, 1981).

Alewife are highly abundant in the pelagic zone of Minas Basin during the summer months and are derived from many Atlantic coast stocks (Rulifson et al., 1987; Dadswell & Rulifson, 1994). Gibson and Myers (2003) indicated that the Gaspereau River spawning population may consist of between 200 000 and 1 million adults. The spawning Alewife population in Gaspereau River during 2002-2006 had a mean fork length of 26 cm and a mean age of 4.3 years (DFO, 2007). Alewife is common to abundant in every tributary of the Bay of Fundy with upstream access to spawning habitat.

Blueback Herring*, Alosa aestivalus (Mitchill, 1815)*

Blueback Herring are pelagic fish, very similar in shape and general appearance to the Alewife. Together, the two fish species are commonly known in the Maritimes as "Gaspereau". Blueback Herring spawn in fresh water in the spring during May and June, after which adults return to the sea (Scott & Scott, 1988). Bluebacks spawn 2-3 weeks later than alewives; the beginning of their spawning run typically commences when the run of spawning Alewife is declining (Scott & Scott, 1988). Blueback Herring from numerous North Atlantic stocks migrate north and south annually, growing at sea until they reach maturity at 4-5 years. Mean lengths for mature Blueback Herring in the Bay of Fundy are 26.9 cm and 28.1 cm for ages 4 and 5 years, respectively (Jessop et al., 1983).

Adults and juveniles are captured in intertidal weirs from April to December; however, the majority of movement into Minas Basin occurs from March to July (Dadswell, 2010). Bluebacks are commonly to abundantly present in most tributaries of the Bay of Fundy. They are highly abundant in the pelagic zone of Minas Basin during summer and in weir catches in July and August (Dadswell, 2010).

American Shad*, Alosa sapidissima (Wilson, 1811)*

American Shad are an anadromous, pelagic fish common in all Bay of Fundy tributaries with upstream access to spawning habitat (Dadswell et al., 1983). Adult shad spawn in fresh water during May to June and then return to sea. Age at maturity varies from 3-6 years, and males typically mature earlier than females (DFO, 2003). Shad typically spawn for the first time at 5 years of age and range in length from 45.7-48.3 cm (Scott and Scott, 1988).

Shad of all ages are highly abundant in the upper Bay of Fundy during the summer months (Dadswell et al., 1983). The population consists of migratory stocks from rivers all along the Atlantic seaboard (Dadswell et al., 1987). The shallow coastal waters of the upper Bay of Fundy is the traditional location for fishing shad, mainly with gillnets or intertidal weirs, as has been the case for more than a century and a half (Perley, 1852). Intertidal weirs typically catch shad during May-August (Dadswell et al., 1984a).

Atlantic Herring, *Clupea harengus (Linnaeus, 1758)*

Atlantic Herring are a marine, pelagic species often found schooling in both shallow inshore waters and offshore waters, occurring from the surface to depths of 200m (Scott & Scott, 1988). Atlantic Herring are common to highly abundant in all parts of the Bay of Fundy. Herring of different life stages, including spawning adults, juveniles, and larvae are common to Minas Basin (Dadswell, 2010). Adults gather in Minas Basin during May to spawn (Bradford & Iles, 1993). Large juveniles form aggregations in Minas Basin during the early parts of summer and are often referred to as 'June herring' (Perley, 1852; Bradford, 1987). Atlantic Herring spawn also spawn in the Scots Bay area and Minas Channel (Bradford & Iles, 1992).

Atlantic Herring are captured frequently in Minas Basin intertidal weirs during spring and summer, often in high abundances (Bradford, 1987; Bradford & Iles, 1993). Bradford and Iles (1993) estimated that the biomass of the spawning stock of the spring spawning group in Minas Basin was 500 MT. Dyer et al. (2005) estimates the biomass of the summer spawning group in Minas Channel to be approximately 75 000 MT.

Atlantic Tomcod, *Microgadus tomcod (Walbaum, 1792)*

Atlantic Tomcod is an anadromous benthic species. They are highly abundant in turbid regions of the upper Bay of Fundy and commonly captured in intertidal weirs in Minas Basin (Dadswell et al., 1984a). Tomcod are common to the inshore, shallow waters of Minas Basin, entering brackish or fresh waters in winter during spawning migrations (Scott & Scott, 1988). Bleakney and McAllister (1973) indicate that adult tomcod tend to remain in the nearshore environment. Pelagic larvae occur in large concentrations in Minas Basin during summer (Bradford, 1987). The life expectancy of tom cod is less than 4 years and they seldom exceed 24 cm in length (Salinas & McLaren, 1983; Dadswell et al., 1984a).

***Atlantic Sturgeon**, Acipenser oxyrinchus Mitchill, 1814*

The Atlantic Sturgeon is a demersal, large bodied, anadromous species which enters river estuaries to spawn in spring and summer (Wehrell et al., 2008). Atlantic Sturgeon are common in Minas Basin during summer, with an estimated 10 000 individuals, of primarily juveniles (1-2 m in length), aggregating each year (Wehrell et al., 2008). Adult Atlantic Sturgeon are known to reach 4.6 m in length (Scott & Scott, 1988) but sturgeon greater than 2.5 m are rarely captured in Minas Basin (M. Dadswell, pers comm,).

Atlantic Sturgeon appear in weirs along the north shore of Minas Basin during April and May, and move throughout the Basin and Southern Bight during July and August (Wehrell et al., 2008). These fish feed on benthic invertebrates and small fishes in the subtidal and intertidal zones (Scott & Scott, 1988). They commonly feed over the Minas Basin mudflats at high tide (Armitage & Gingras, 2003) and are frequently present in intertidal weir catches (Wehrell et al., 2008; D. Porter, pers. comm.).

***Atlantic Mackerel**, Scomber scombrus (Linnaeus, 1758)*

Atlantic Mackerel are marine, pelagic fish that are highly migratory and display strong schooling behaviour (Scott & Scott, 1988). During spring and summer, Atlantic Mackerel are found in inshore waters. They typically appear in Minas Basin during May to August (DFO, 2012; Dadswell, 2010). They are commonly to abundantly present in most pelagic zones of the entire Bay of Fundy, except in regions of high turbidity (Dadswell et al., 1984a). Sexual maturity may be reached at an age of 2 years and approximately 30 cm in length, but most mackerel are sexually mature by age 4 and an estimated 34 cm. Large catches are often made outside Minas Basin in Scots Bay, but they are less common inside Minas Basin (Dadswell, 2010).

Rainbow Smelt, *Osmerus mordax (Mitchill, 1985)*

Rainbow Smelt are a small, anadromous species that are extremely abundant and common in coastal waters in all regions of the upper Bay of Fundy (Dadswell et al., 1984a). Adults are pelagic and are present in estuaries and along shorelines during spring to fall. Spawning occurs in the spring, as smelt ascend freshwater rivers and streams, including Gaspereau River in late April, and Portapique River in early May (Dadswell, 2010). There is no directed commercial fishery in Minas Basin; however, smelt are often captured in intertidal weirs and by recreational fishers. Mature 2 and 3-year-old smelt (13 – 20 cm), make up the majority of the catches, although 4 and 5-year-old smelt are also caught (Scott & Scott, 1988).

Striped Bass*, Morone saxatilis (Walbaum, 1792)*

Striped Bass are anadromous, pelagic fish, and are abundant in the upper Bay of Fundy, especially in the Minas Basin (Rulifson et al., 2008). They inhabit the nearshore environment, moving into estuaries and freshwater to feed and spawn. A large spawning stock occurs in the Shubenacadie River and spawning occurs in the spring during May-June (Scott & Scott, 1988). The Bay of Fundy supports a summer aggregation of Striped Bass consisting of Canadian and USA stocks (Rulifson & Dadswell, 1995). There is no longer a commercial fishery for Striped Bass, however, a by-catch of one bass (≥68 cm TL) per day is permitted. Striped Bass captures in intertidal weirs are common during April-September and include both juvenile and adults (Dadswell, 2010). Currently, there are several studies underway to gather information on different aspects of Striped Bass, including population structure and movement patterns in Minas Basin. Due largely to a decline in spawning habitat, COSEWIC has recommended endangered status for the Bay of Fundy Striped Bass population (COSEWIC, 2012)

***Windowpane**, Scophthalmus aquosus (Mitchill, 1815)*

Windowpane, a flatfish also known as "Old Maid", is a marine, benthic species and common throughout the Bay of Fundy, especially over sandy substrate (Scott & Scott, 1988). They reach maturity at approximately 3-4 years of age and 23-25 cm in length (Scott & Scott, 1988). Individuals of the upper Bay of Fundy may reach lengths up to 43.2 cm, with a maximum-recorded length of 45.7 cm (Scott & Scott, 1988). They are most abundant during the summer months, but may occur year round (Wehrell, 2005). Windowpane is very abundant in Minas Basin and can be one of the most abundant fish species in intertidal weir catches (Bousfield & Liem, 1959).

***Smooth Flounder**, Liopsetta putnami (Gill, 1864)*

The Smooth Flounder is a benthic fish found in inshore, shallow waters and are sometimes referred to as "smooth backs" (pers. comm., D. Porter). This species is frequently found in estuaries and is common to warm water habitats throughout the Bay of Fundy (Scott & Scott, 1988) and is abundant in Minas Basin (Dadswell, 2010). Smooth Flounder is the smallest of the flatfishes in the Bay of Fundy; the maximum recorded length is 32.3 cm (Scott & Scott, 1988). Due to its small size in relation to other flatfishes, and its restricted inshore distribution, the Smooth Flounder is not generally commercially fished in Canada (Scott & Scott, 1988).

***Winter Flounder**, Pseudopleuronectes americanus (Walbaum, 1792)*

Winter Flounder is the most abundant flounder species in the Bay of Fundy (MacDonald et al., 1984). They move offshore in the winter and onshore during the summer (Scott & Scott, 1988). Winter Flounder spawn inshore in May and grow rapidly. Maturity is reached between 3 and 4 years of age, at which time flounder range in length between 20-25 cm depending on the individual's sex (Scott & Scott, 1988).

Winter Flounder are present in Minas Basin between April and October (MacDonald et al., 1984) and peak in abundance in during July (Wehrell, 2005). They are commonly captured in intertidal weirs (Dadswell, 2010) and support both commercial and recreational fisheries in the Bay of Fundy (Simon & Comeau, 1994).

SITE DESCRIPTION AND METHODOLOGY

Minas Basin, Bay of Fundy

The Bay of Fundy is an arm of the Gulf of Maine that lies between the provinces of New Brunswick and Nova Scotia. Resonance of standing waves, primarily caused by the shape of the Bay of Fundy, and a slightly longer period than the normal semi-diurnal tide, combine to produce the largest tidal amplitude in the world (Karsten et al., 2008). The tide, which rises and falls twice daily, is regulated primarily by the semi-diurnal lunar (M2) tidal constituent, and has a period of 12.4 hours.

The study area is located in Minas Basin in the upper Bay of Fundy (Figure 1). Annual temperatures range from a peak of 16-20°C in August-September to 0-1°C in winter months (Dadswell, 2010). Minas Basin is a highly dynamic, hypertidal estuary that experiences extreme tidal amplitudes reaching up to 17 m (Oceans Ltd., 2009). The tides result in rapid tidal currents that can exceed 6 m/s as well as widespread mixing of the water column (Lotze & Milewski, 2002). The well-mixed waters are highly productive. Minas Basin supports a diverse fish assemblage including both resident and migratory species. Originating from stocks derived over the entire North American Atlantic coast, large numbers of migratory fishes, and other marine life, frequent the Bay of Fundy annually (Dadswell & Rulifson, 1994). As consequence of its tidal amplitude, an extensive intertidal zone characterizes the Minas Basin. The intertidal zone is comprised of vast mudflats, which span 1-3 km from the shoreline. In many areas, the upper reaches of the intertidal zone feature dense salt marsh environments. Other distinguishing features include high concentrations of suspended sediments and low water transparency (van Proosdij & Baker, 2007). Salinity varies between 26-30 ‰ in the Minas Basin due to incoming freshwater from the Avon, Shubenacadie and Salmon Rivers (Lambiase, 1980; Yeo & Risk, 1981). The geological composition of the seabed of the upper Bay of Fundy is composed of coarse Triassic red beds and fissile carboniferous slates, with each region displaying varying proportions of mud, and gravel (Yeo & Risk, 1981).

Intertidal Weirs

Intertidal weirs (including trap nets) have been a prominent method of fishing within Minas Basin, especially during the nineteenth century when they were used extensively to fish herring, salmon and shad. A "Trap Net" encloses an area of water, into which fish are guided by a long leader through (an) opening(s). A traditional "Weir" differs from a "Trap Net" in that it is constructed using brush and netting, and consists of a holding pool into which one or more leaders guide fish. Weir operators frequently design their weir to primarily target a specific fish species or group of fishes. The structures vary in both height and width. The heights of the nets typically range between 3 – 4 m, but may exceed this height. The lengths of the wings of both weir types are usually vast, ranging between 100 – 700 m.

The intertidal weirs used as sampling platforms in this study (described in detail in a later section) include a traditional brush weir and a modern weir featuring a trap net. Determination of the weir sites selected for this study was dependent on the location of the weir, and the weir operators' willingness to participate in the project. Of the four weir fishers contacted, two agreed to participate, allowing access to weir catches on both the northern (Five Islands, NS) and southern (Bramber, NS) shores of Minas Basin (Figure 1).

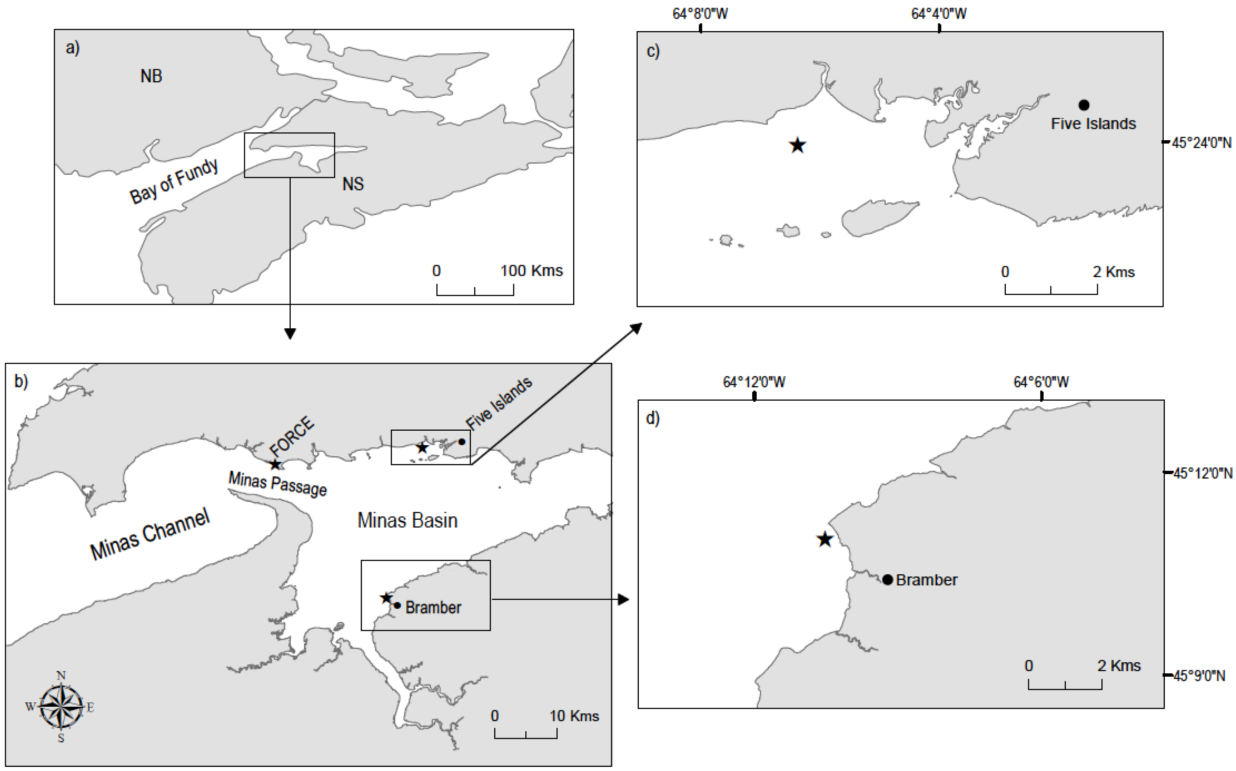


Figure 1: Maps of a) Nova Scotia and Bay of Fundy, b) Minas Basin, Minas Passage and sampling sites, c) Five Islands and weir site (*), and d) Bramber and weir site (*).

An intertidal weir is constructed by driving hundreds of wooden stakes deep into the mud of the intertidal zone at low tide. In most weirs, mesh netting is attached between the stakes, stabilized by a continuous layer of rocks along the base. During each tidal cycle, weirs are completely submerged during high tide and become exposed during low tide. This method of inshore fishing aims to catch fishes as they move out of the nearshore environment on the receding ebb tide. Weirs in Minas Basin vary in design, size, and arrangement; however, the functionality of all intertidal weirs is similar. Weirs are placed at strategic locations, in the shape of a "V", "U", or "J". The structures feature one or two wings that extend towards the shoreline with the intention of intercepting the natural path of the fish, guiding them towards the mouth of the weir (Figure 2). The mouth, or center, of the weir normally features a large circular pool where fish are retained as the receding tide drops below the netting. Fish are collected from the volume of water that pools in the mouth of the weir, twice daily, during low tide. Using a seine or dip-net, fishermen retrieve the catch; commonly a door or gate is positioned in the center of the trap to allow the fisher to drain the pool and collect fish. Fishermen retain commercially valuable fish, while non-targeted species (by-catch) are returned to the pool to be released on the next incoming tide. Intertidal weirs in the upper Bay of Fundy generally remain in place for approximately six months. Typically, weir construction begins in the spring (March/ April) and the traps are fished until late summer or early fall.

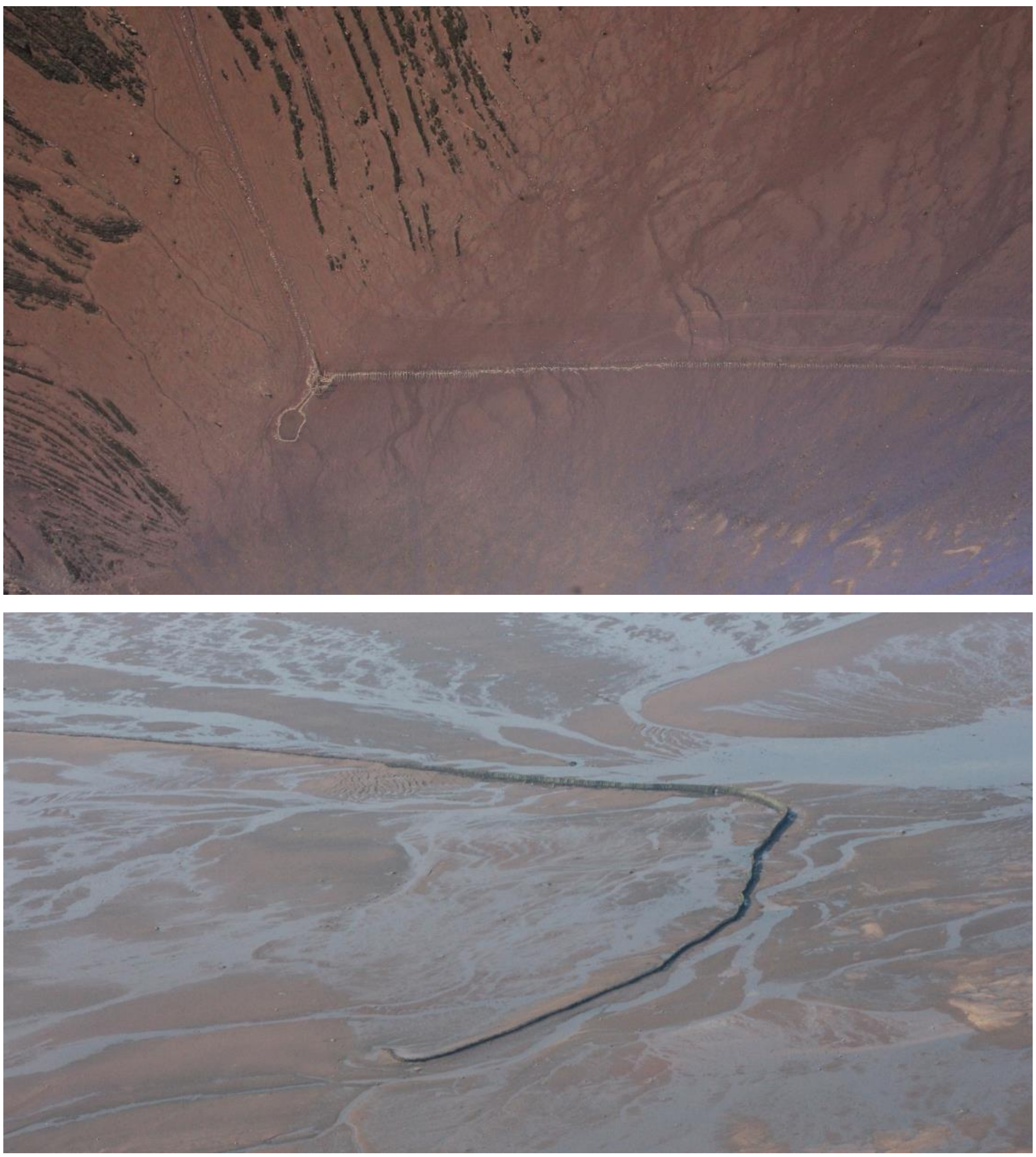


Figure 2: Aerial photographs of the two intertidal weirs, Bramber (top) and Five Islands (bottom), depicting the shape of each structure.

Field Sites & Intertidal Weir Specifics

Five Islands Weir

The intertidal weir on the northern shore of Minas Basin was located near Five Islands, Nova Scotia (45°39864, -64°10588), halfway between the high water mark and the Five Islands (Figure 3). The weir was positioned within a drainage channel along a gently sloped intertidal zone composed of gravel, mud and sand. This weir is licensed as a Flounder weir, indicating that Flounder (American Plaice, Winter Flounder, Witch Flounder and Yellowtail Flounder (including other members of the order Pleuronectiformes)) are the principal fishes targeted by this trap. While the weir is licensed as a Flounder weir, this does not limit the fisher to only retaining Flounder as each commercial weir has specific license conditions, exclusive to that weir, that are managed and enforced by DFO.

The Five Islands weir is a traditional brush weir. The broad trap is V-shaped; one wing stretches towards the shoreline, while the other extends towards the islands (Figure 2). The skeleton of the structure is composed of hardwood pilings, typically birch or maple, pounded into the intertidal zone. The pilings vary in height (1.0-2.5 m). The height of the weir gradually increases from the wings' ends to where they converged, forming the trap's mouth (2.5 m high). Netting, 1 ½ inch stretched, is attached between each of the poles along the entire length of the structure. The base is comprised of multiple layers of very thick and long coniferous (mainly spruce) branches, woven between the pilings, and numerous heavy rocks at each piling's base (Figure 4). The total length of the weir in 2013 was about 580 m.

Sediment transport due to tidal currents resulted in significant accumulation on the inside of the weir.. The structure was completely submerged near/at high tide and exposed near/at low tide. At times, when the low tide level was ≥ 2.5 m in relation to the seafloor, the weir site remained partially inundated and fish could not be collected.

Figure 3: Aerial photo showing the positioning of the Five Islands weir in the intertidal zone relative to the islands in the area.

Figure 4: Photo showing the structural composition of the Five Islands weir.

The weir structure was normally exposed during low tides but did not drain dry due to the formation of multiple deep pools within/near the mouth of the trap. Tidal currents, weir design, and the strategic placement of rocks resulted in areas of deposition and erosion. As the tide ebbed and the water level dropped below the height of the weir, fish were concentrated in three pools of tidal water - one large pond in the mouth of the structure, and two smaller ones along the seaward wing.

Bramber Weir

The larger and more complex of the two weirs in this study was located in the Southern Bight of Minas Basin near Bramber, Nova Scotia (45°39865, -64°10585), just outside the mouth of the Avon River estuary, approximately 23 km downstream from the Avon River Causeway in Windsor, NS. Three main rivers contribute to the flow and circulation of the estuary - the Avon, Kennetcook and St. Croix Rivers. Collectively, these rivers supply 87% of the estuary's total drainage (Whidden, 2013). Smaller rivers in the area include the Cogmagun, Herbert and Halfway Rivers.

The Bramber weir was positioned within a very gradually sloping intertidal zone, comprised primarily of mud, sand, and gravel (van Proosdij & Baker, 2007). The licensed target species at this site was Atlantic Herring, *Clupea harengus*; however, captured and retained fish were not limited to the target species.

The Bramber site featured a modernized version of an intertidal weir, which included a trap-net and multiple types of netting/fencing. The weir structure was expansive, consisting of a fully enclosed trap net between two wings. A rectangular pattern of wooden pilings driven into the mud formed the frame of the trap net. The body of the trap net stood 3.5 m high, 6 m wide, and 11 m deep, and was encompassed entirely in 1 ½ inch stretched netting. The lower regions of the trap net also included snow fencing to provide additional strength and both water and fish retention. The trap net featured two narrow openings, one leading to each of two divisions, both of which were ≤ 1 m in width (Figure 5). The base of the trap net was created using wooden boards attached directly to the pilings and was secured using rocks and sandbags. The thick foundation of the trap net enabled receding waters to pool in the mouth of the weir, concentrating the catch. The seaward face of the trap net included a gate near the base, which allowed water to be drained and fish to be collected using dip nets (Figure 6).

Figure 5: Bramber trap net opening and pool, seaward facing.

Figure 6: Bramber weir trap net and gate used to drain water and collect fish.

The central trap net was positioned between two tall wings that acted as leaders to guide fish towards the opening of the trap net. The weir was situated along the northern edge of a cove and the wings were aligned to intercept the natural path of fishes leaving the nearshore with the ebbing tide. The shorter of the two wings ran perpendicular to the shoreline from the mouth of the trap for 180 m. The other wing ran parallel to the shore from the trap net for 600 m, before curling back on itself in the shape of cane. The total length of the longer wing was 670 m. Both wings were constructed by positioning large softwood pilings deep within the mud at low tide using a tractor and an auger. Running the distance of both wings, 1½ inch netting was fastened to the pilings. A layer of brush, interwoven between pilings and covered with a heavy layer of rocks comprised the base. A row of hardwood branches (birch) was attached to the top of the netting. Each wing stood 3 m high for 120 m on either side of the trap net, and then dropped to 2.5 m in height for the remaining length of each wing (Figure 7).

The difference in the overall height of the Bramber weir in relation to that of the Five Islands weir reflects the target species. Herring are pelagic fish and the Bramber trap was constructed to target these fish, which swim much higher in the water column than Flounder. The longest wing also featured a gate, like that of the trap net, in its center. This gate was installed in July to assist in fish collection, as both water and fishes concentrated in this area. The positioning of the structure within the intertidal zone resulted in it being completely submerged during high tides and fully exposed during low tides. In contrast to the Five Islands site, the Bramber weir did not experience occasions where the area remained partially flooded during neap tides. Seaward of the weir, a pond was creating for the purpose of holding released by-catch after water had been drained from the trap net and wing. The 23 m by 8 m holding pond was connected to the backside of the trap net by an 18 m long channel, approximately 1m deep (Figure 7).

Figure 7: Bramber weir central trap and long wing (top), and the central trap, inner portions of the two wings, and the holding pond (bottom).

Seasonal Sampling

Seasonal sampling included 42 individual low tide catches, 22 tides at the Bramber site and 20 at the Five Islands site. Intertidal weir catches were sampled on a near weekly basis during daytime low tides. Sampling commenced in early April at Bramber and in early May at Five Islands. Tables 1 & 2 display the dates when sampling was conducted. Sampling was conducted during the daylight (hours between sunrise and sunset) in an effort to make sampling efforts comparable. Occasionally, consecutive tides within a 24-hour period were sampled at the Five Islands weir depending on the times of low tide. Both weir operators ended their fishing season in early August when catches of commercial species diminished.

During each sampling occasion, effort was made to identify all fish species in the catch and estimate their abundance. Fish <7 cm were infrequently present in the catch, as they were capable of passing through the netting and/or escaping the weirs. Fish were identified to species level where possible using the physical descriptions presented in Scott and Scott (1988), and if needed, were confirmed by weir operators.

Overall abundances of each species present in the catch were determined by counts or derived from total weights (lbs.) provided by the fisher. A random subsample of each captured species was collected for length (cm) and weight (g or lbs.) measurements. A standard measuring board was used to collect total and fork lengths (cm); both a spring scale (300g) and an electronic scale (30 lbs.) were used for weighing fish.

Size of random subsamples was dependent on several factors: 1) size of the overall catch, 2) number of different fish in the overall catch, 3) number of fish to be released, 4) available time for sampling (tidal stage), and 5) the activities and schedule of the fisher.

Subsamples were taken for two purposes: 1) to determine sizes of captured fishes and 2) to establish the proportion of different species pooled together by fishers during the sorting process (see Appendix I).

Normally, if the abundance of a captured species was low (<25 individuals), all individuals were measured. Where the abundance of a species was moderate (>25, but less than 200 individuals), the subsample was obtained by random selection of between 25 and 50 individuals for measurement. Generally, commercial fishes were relatively abundant in the weir captures. These fishes were retained by the fisher and sorted into commercial groupings that often featured more than one species (e.g. Gaspereau). A random subsample of approximately 50 individuals was taken from these multi-species groupings for measurement and to determine relative abundance.

The sampling protocol was comparable between the two weir sites; however, the physical differences in the two weirs did influence how the fishers collected their catch. The different methods of collection created certain distinctions between how sampling was conducted at each site (see Appendix I).

Estimating Abundance

Counting of individuals, visual assessments, or total weights of commercial fish were used to estimate a species' abundance. Species that were rarely captured or captured in low abundance were typically counted to estimate abundance. This approach was commonly applied to the by-catch. By-catch fishes that were captured in moderate to high abundance were often estimated using visual observation. This method was commonly used for young-of-the-year stages of fishes, particularly Atlantic Herring and Rainbow Smelt, which are not easily collected by the weir operators' collection methods. Commercial species, which were retained by the fisher, were frequently captured in moderate to high abundance. The abundances of these species were estimated using counts, if efficient, or were derived from the total weight measurements. The mean weight and proportion of each species present within each commercial grouping was determined through random subsampling. The ratio of a species in a particular grouping was used to approximate the total weight of that species from the grouping's overall weight. By dividing the total weights of each species by their respective mean weights, the abundance for an individual species was estimated.

Diel Comparison Sampling – Bramber Weir

Additional sampling was conducted to characterize diel trends in weir catches at the Bramber site. Lasiak (1984) and Gibson et al. (1996) identified significant variation in fishes captured in nearshore environments in response to the time of day at which low tide occurred. Sampling was completed during the month of July, which featured day and night sampling of 14 consecutive tides over a 7-day period (12-19 July) to examine the influences on abundance. The sampling protocol was consistent with the procedure used during the near-weekly sampling; however, the night tide catch of 15 July was overwhelmingly large and the fisher required assistance to collect and release the catch. Specifically for this tide, morphometric data was not collected and by-catch species were not enumerated. Data collected included species identification, estimates of by-catch species abundance, and overall weights of commercial groupings. The proportion of species within each grouping was estimated by visual observation.

During 30 July – 6 August, a second set of day/night observations in the form of total weight of each commercial grouping over 16 consecutive tides, were recorded by the fisher. No day/night sampling was conducted during this period; however, two daytime tides (1 & 6 August) sampled as part of the seasonal sampling overlapped with this period.

Environmental Sensors

Prior to the start of weekly sampling of the weir catch, environmental sensors (HOBO Pedant Temperature Logger and HOBO U20 Titanium Water Level Data Logger) were installed in or near each weir. These devices were utilized to examine the variability in high tide height and water temperature during the study.

At both the Five Islands and Bramber weir sites, these recording devices were attached directly to the weir structures, near the center of the traps, and recorded data at 15-minute intervals (Figure 8). Both devices remained at the sites continuously until October 2013, except for brief periods of temporary removal to change depleted batteries, replace memory cards or perform interim data downloads (see schedule of activities in Table 3).

Acoustic Monitoring of Fishes

Acoustic Telemetry

A VEMCO VR2w acoustic telemetry receiver was deployed near each weir to detect and record the presence of Atlantic Sturgeon and/or Striped Bass that had been previously implanted with acoustic transmitters for existing co-funded FORCE projects. Acoustic receivers were mounted on rebar and positioned in close proximity to the hydrophones at each weir site (Figure 8). The acoustic receivers recorded transmissions emitted from any acoustically tagged fishes that were near to the weir sites. This data was forwarded to the principle investigators of the fish-tracking program.

Acoustic Zooplankton Fish Profiler (AZFP)

For two 1-week intervals in July and early August, a single-beam sonar (AZFP, ASL Environmental Sciences) was attached near the center of the long wing of the Bramber weir. Dr. Gary Melvin of DFO's St. Andrews Biological Station (SABS) provided the instrument and assisted with installation. The AZFP monitored the presence and the depth of identified targets (fish) within the water column by measuring the volume of acoustic backscatter returns using ultrasonic frequencies. The AZFP unit consisted of two transducers, which were positioned on the landward side of the weir (Figure 8). A battery/data storage pack was attached to one of the braces supporting the weir wing. The transducers were placed within a depression to ensure they would stay wet. Each transducer generated a 7° beam of one 'ping' per second at a frequency of 125 kHz. The unit was located approximately 300 m from the central trap net.

At the time of preparing this report, the analysis of AZFP data was underway but not yet complete; the results will be presented in a later stand-alone report.

RESULTS

Water Temperature & Tide Height

Figures 9 & 10 show temporal patterns in water temperature and tide height at the two weirs. At high tide, water temperature at both weir sites increased from 2.5°C in early April to a high of 19°C in late August. Tidal range varied between 8-12 m at the Bramber site and 9-12 m at the Five Islands site.

Fish Composition in Weir Catches

A total of 28 fish species were identified in weir catches over the 2013 season (Tables 4 & 5). Of the 28 fish species identified, 24 were captured at the Bramber weir and 22 were captured at the Five Islands weir. More than 6300 fish were sampled during the near-weekly surveys. An additional 14 sampling events occurred at the Bramber site during the intensive sampling period. These extra surveys yielded approximately 2000 additional fish measurements.

Weir catch composition was variable throughout the sampling season. Variability in species richness and the relative abundance of each species within the overall catch can be attributed to the seasonality and spawning habits of certain species, as well as the effectiveness of each weir. Catches consistently featured large proportions of fish from the Clupeidae family and order Pleuronectiformes or flatfishes. Most regularly captured members of the Clupeidae family were those of genus *Alosa* (Table 1 & 2). Atlantic Herring, *Clupea harengus*, was also a common species present in the weir catches.

Fish Presence

The seasonal abundance of 12 species is shown in Figures 11 – 21. They include frequently captured species, species captured in large abundance, commercially relevant species, and COSEWIC or SARA listed species. Of these twelve, captures of Atlantic Tomcod, smooth flounder, and Windowpane at the Five Islands weir were rare and thus not plotted for visual assessment. In each case, the time of the sampling event was classified as either "Daytime" or "Dawn". Daytime referred to sampling events that occurred after the sun had fully risen (i.e. fish captured in the weir during daylight hours). Dawn referred to sampling events that took place during sunrise, but before the sun was fully above the horizon. This indicates that fish would have been captured in the weir during twilight. The weir effectively captured fish after the water level dropped below weir nets, approximately 1-2 hours before the weir was accessible to the fisher (Porter pers. comm.).

Fish Size

The number of individuals of each species sampled throughout the study differed between the two weir sites. For comparison of the length frequencies of the same species captured at both Bramber and Five Islands sites, sample sizes were normalized (i.e. common scale). Length frequency distributions for the 12 main fish taxa are shown in Figures 22-33.

Standard length-weight relationships for 10 of the 12 main fish species from Bramber and 7 of the 12 species from Five Islands were produced using natural logarithm transformations of the measured total lengths (cm) and weights (g). Linear regression equations and coefficient of determination values can be found in Table 6. Length-weight relationships are shown in Appendix II. Weight measurements were unavailable for Atlantic Sturgeon and some Striped Bass, as individuals were too large for the scale. Julia Whidden, an Acadia MSc. student studying Striped Bass at the Bramber weir, provided morphometric and abundance data for Striped Bass, although weight was not commonly recorded. Length-weight relationships were used in estimating the abundance of captured fishes on a few occasions when weight data was absent or when the scale was found to be unreliable.

Diel Patterns in Weir Catches

During two 1-week periods, the total weights (kg) of captured commercial fishes were examined for differences in catch abundance between daytime and nighttime tides (Figure 34). Fishes considered as "commercial" included Alewife, Blueback Herring, Winter Flounder, Windowpane, Smooth Flounder, and American Shad. Insignificant contributions to the total weight by smaller fishes contained in the mixed grouping potentially included Rainbow Smelt, Atlantic Tomcod, and young-of-the-year (YOY) Atlantic Herring. Data on total weight (kg) of captured commercial fishes, through 12 July – 19 July, was collected during the intensive sampling period. During 30 July – 6 August, which coincided with the 2nd deployment of the AZFP, total weight (kg) information on captured commercial fishes was provided for each tide by the Bramber weir fisher.

The abundance of fish captured during daytime and nighttime tides differed greatly, with greater catches during nighttime, during both of the intensive day/night sampling periods (Figure 34). These sampling periods occurred during neap tides in July and early August, 2013. Catch abundances were much greater during mid-July than during early August.

General Observations on Fish Abundance and Size Frequency

The abundance of captured fish at both weir sites was variable throughout the sampling season, likely due to the time of day when sampling occurred and environmental factors. Near-weekly sampling occurred only during daytime or dawn hours, which showed smaller catches than those during nighttime (intensive sampling periods). Both weir fishers indicated that weather conditions may affect the abundance of fish in the weir catch, and/or the species captured. In particular, windy conditions during daytime low tides might influence American Shad abundance in weir catches (Porter pers. comm.). Cloud cover during daytime low tides might also impact catch abundance by affecting where fish position in the water column (Porter pers. comm.). Weir catches are generally less abundant following thundershowers (Lewis pers. comm.). Both weir fishers indicated that the abundance of American Shad captured during summer months in 2013 was lower than anticipated. While the abundances of Atlantic Sturgeon and Striped Bass were low in catches during near-weekly sampling events, both species were commonly captured throughout the summer months at Bramber and in the spring to early summer at Five Islands. During an 8 week period through June and July, Atlantic Sturgeon were present in the Bramber weir catch on almost every tide and as many as 12 were captured in a single tide (Porter, pers. comm.).

Abundances of the main fish taxa were generally greatest from mid-April to mid-May, and again from mid-June to early July when water temperature ranged from 12-14°C. Species richness was greatest at both the Bramber and Five Islands sites during late June and July, peaking at 17 and 12 species, respectively (Figure 35). The size frequency of larger bodied fishes in the weir catches generally declined as the study progressed. Spring catches consisted primarily of mature adults and the summer catches consisted mainly of sub-adults, juveniles, or YOY life stages. There did not appear to be strong relations between individual species abundance in the catch and water temperature or high tide height throughout the sampling season. However, the number of tides sampled may have limited the ability for any relationships to be determined. Fluctuations in overall catch biomass may be related to tidal range and the spring-neap tidal cycle. Figure 36 displays the combined abundance of all captured fishes at each site and peak captures tend to occur before or after spring tide events. General observations on abundance and size frequency for each of the 12 main fish taxa can be found in Table 7.

CONCLUSION & RECOMMENDATIONS

Commercial intertidal weirs were found to be highly useful platforms for monitoring fish assemblages of commercial and non-commercial fishes, including seasonal and diel trends in fish abundance, species richness, and size frequency. While neither of the weirs included in this study was located directly within Minas Passage, data collected from catches in the two weirs provided pre-turbine baseline data on a wide range of fishes, including species known to migrate through the Minas Passage.

Intertidal weirs have the potential to be used for long-term monitoring of fishes, including natural fluctuations in species richness and abundance in the region. Because weirs are generally positioned in the same location and are constructed in a similar fashion each year, year-to-year catch data should be comparable. In contrast to previously used monitoring techniques, including trawling vessels and hydroacoustic sonar surveys that represent short time frames, intertidal weir catches provide the opportunity to monitor fish presence at various time intervals over approximately 5 months. In addition, catch surveys are not dictated by weather, time of day or tidal currents. Although mesh size of the netting limits data collection to fish >6 cm total length (this study), weirs are less selective than other methods (e.g. gill nets), as they have the potential to trap most species present in the water column of the nearshore environment. Tidal conditions may restrict some low tides during neap periods from being sampled, depending on the location of the weir in the intertidal zone. Low-running neap tides may not fully recede from the mouth of the weir denying fisher access. In addition to the monitoring of weir fish catches, weirs offer opportunities for acoustic sensing of other marine life, including predators like the Harbour Porpoise (see later section).

While weirs are a low cost alternative to collecting biological data, no two weirs are the same. Each weir in the upper Bay of Fundy is unique in structure and is licensed to target a specific species, which influences weir design and position relative to shore. These factors make it difficult to compare the abundance of captured fishes between sites. If intertidal weir surveys are included in future monitoring studies for FORCE, it is recommended that more than two intertidal weirs be included (dependent on fisher participation) with weirs closest to the FORCE test site being most directly relevant.

During this study, catches at intertidal weir sites were sampled approximately once per week during daytime low tides. While seasonal patterns can be recognized through weekly sampling, it limits the detection of sporadic events. Peak abundances in weir catches may occur over a short time frame. For example, fisher catch records show that the peak captures of Atlantic Herring and Atlantic Mackerel did not coincide with the near-weekly sampling events. If intertidal weir sampling is to be a part of future monitoring programs, it is recommended that the frequency of sampling events be increased to capture rare but significant events.

Data from the intensive sampling periods in mid-July and early August suggested a strong relationship between fish captures and the time of low tide. Fish abundance in the intertidal zone during twilight and nighttime may be greater, or the weir may fish more effectively in the absence of light. It is recommended that the relationship between time of low tide and weir catches be further explored. The inclusion of more seasonal sampling events, which include evenly distributed numbers of daytime and nighttime samples or sampling consecutive tides on a weekly or shorter basis, is recommended.

This study addresses some gaps in the EEM program for FORCE, as outlined by DFO’s 2012 Science Response Review (DFO, 2012). The response mentioned the importance of understanding baseline conditions of the ecosystem, and basin-wide biological features. Valuable data can be collected from weir catches to augment existing studies prior to tidal energy development. Specifically, data related to the age and size distribution of Minas Basin fishes and temporal trends in species presence and abundance can be identified. It is recommended that for future intertidal weir monitoring studies, the sampling protocol be refined to better address patterns in fish presence and abundance, and that multiple weir sites within Minas Basin and Minas Passage be sampled to account for differences in weir size and design. Alternatively, an experimental weir located in Minas Passage, could be developed and used for scientific purposes, including assessments of the timing of fish presence in the passage.

Table 1: Bramber weir sampling events between April and August 2013. Intensive one-week sampling event not included here. Catches are shown in Figures 11-21 and Table 4.

Date (dd/mm/yyyy)	# Species Captured	Main Taxa Captured	Total # Fish Measured
4/04/2013	6	Tomcod, Smelt	188
9/04/2013	9	Herring, Tomcod	252
12/04/2013	11	Tomcod, Smelt	173
16/04/2013	10	American Shad, Alewife	222
18/04/2013	10	American Shad, Alewife	213
23/04/2013	8	American Shad, Alewife, Winter Flounder	149
1/05/2013	10	Alewife, American Shad	209
8/05/2013	10	Winter Flounder, Alewife	180
19/05/2013	10	Alewife, Winter Flounder	162
24/05/2013	12	Herring, Alewife	133
29/05/2013	14	Alewife, Winter Flounder	147
4/06/2013	12	Winter Flounder, Alewife	144
13/06/2013	10	Winter Flounder, Windowpane, Blueback Herring	213
18/06/2013	13	Alewife, Winter Flounder	150
27/06/2013	16	Alewife, American Shad	236
2/07/2013	9	Mackerel, Winter Flounder	129
12/07/2013	17	Winter Flounder, American Shad	172
17/07/2013	10	Blueback Herring, Alewife	190
25/07/2013	11	Alewife, Blueback Herring, Windowpane	175
1/08/2013	11	Herring (YOY), Winter Flounder	126
6/08/2013	13	Smelt, Tomcod	168
12/08/2013	9	Smelt	101
			3832

Table 2: Five Islands weir sampling events between May and August 2013. Catch data are shown in Figures 11-21 and Table 5.

Date (dd/mm/yyyy)	# Species Captured	Main Taxa Captured	Total # Fish Measured
2/05/2013	6	Alewife, Herring	131
7/05/2013	11	Smelt, Alewife	111
16/05/2013	10	Alewife, American Shad	128
17/05/2013	10	Herring, Alewife	96
22/05/2013	9	Herring, Alewife	130
23/05/2013	9	Herring, Winter Flounder	81
30/05/2013	11	Alewife, American Shad	159
5/06/2013	12	Winter Flounder, American Shad	121
6/06/2013	8	Alewife, Blueback Herring	119
14/06/2013	9	Blueback Herring, American Shad	130
20/06/2013	12	Mackerel, Herring (YOY), American Shad	181
21/06/2013	12	Blueback Herring, Alewife, Herring	165
25/06/2013	8	Blueback Herring, Alewife, American Shad	123
26/06/2013	6	Blueback Herring, Alewife	117
3/07/2013	8	Mackerel, Herring (YOY)	163
9/07/2013	7	American Shad, Alewife	116
17/07/2013	6	Blueback Herring, Alewife	106
24/07/2013	9	Herring (YOY), Smelt	102
31/07/2013	11	Blueback Herring, Alewife	80
9/08/2013	7	Herring (YOY), Smelt	41
			2400

Table 3: Field activities in addition to weekly weir catch surveys/sampling, from April – mid August 2014.

Activities at weirs	**Bramber** 45°39865, -64°10585	**Five Islands** 45°39864, -64°10588
Temp & Pressure Sensors – 1st Deployment	April 1& 4	April 24
C-PODs/VEMCO Receiver – 1st Deployment	April 1	April 24
Pressure Sensor – 1st Recovery	May 24	NA
Pressure sensor – 2nd Deployment	May 28	NA
C-PODs – 1st Recovery	NA	June 21
IcListen HF Hydrophone – 1st Deployment	June 27	NA
C-PODs – 2nd Deployment	NA	July 3
Day & night weir catch sampling at Bramber weir	July 12-19	NA
ASL AZFP – 1st Deployment	July 12	NA
ASL AZFP – 1st Recovery	July 19	NA
IcListen HF Hydrophone – 1st Recovery	July 26	NA
IcListen HF Hydrophone – 2nd Deployment	July 29	NA
ASL AZFP – 2nd Deployment	July 29	NA
ASL AZFP – 2nd Recovery	August 6	NA
Temp Sensor – Position Change	NA	August 9
Pressure Sensor – 2nd Recovery	August 12	NA
Temp Sensor – 1st Recovery	August 12	NA
Pressure Sensor – 3rd Deployment/Position Change	August 14	NA
Temp Sensor – 2nd Deployment/ Position Change	August 14	NA
IcListen HF Hydrophone – Last Recovery	September 20	NA
Pressure Sensor – Position Change	NA	September 10
C-PODs, Temp sensor, pressure sensor – Last Recovery	October 7	October 15

Table 4: The presence and relative abundance of identified species captured at the Bramber site at each weekly sampling event. Fishes that were most common are highlighted in bold and their seasonal abundances are plotted in Figures 11 – 21.

Scientific Name	Common Name	Relative Abundance Date (2013)																					
		Apr 4	Apr 9	Apr 12	Apr 16	Apr 18	Apr 23	May 1	May 8	May 19	May 24	May 29	June 4	June 13	June 18	June 27	July 2	July 12	July 17	July 25	Aug 1	Aug 6	Aug 12
Alosa pseudoharengus	**Alewife**	R	L	M	H	H	M	H	M	M	M	H	M	M	H	H	M	M	M	H	L	M	L
Alosa sapidissima	**American shad**	NP	NP	R	M	M	L	M	R	NP	NP	M	L	M	M	M	L	L	NP	L	L	L	R
Alosa aestivalis	**Blueback herring**	NP	NP	NP	NP	NP	NP	NP	NP	H	M	H	M	H	M	M	NP	L	H	H	NP	NP	R
Clupea harengus	**Atlantic herring**	R	M	L	M	L	L	M	L	L	H	L	M	NP	H	H	H	H	H	NP	H	H	M
Pseudopleuronectes americanus	**Winter flounder**	L	L	L	L	M	M	M	M	M	M	M	M	H	M	M	M	M	L	M	L	L	NP
Scophthalmus aquosus	**Windowpane**	NP	R	R	L	L	R	L	L	L	L	M	M	M	L	M	R	L	M	M	NP	L	L
Liopsetta putnami	**Smooth flounder**	NP	NP	NP	NP	R	L	L	R	L	R	L	M	L	L	NP	NP	L	R	M	R	R	NP
Microgadus tomcod	**Atlantic tomcod**	M	M	M	NP	NP	NP	L	M	M	L	L	R	R	NP	M	NP	L	M	M	NP	M	NP
Osmerus mordax	**Rainbow smelt**	L	L	L	L	L	NP	L	L	L	L	L	M	L	M	M	M	M	M	M	M	H	H
Morone saxatilis	Striped bass	NP	R	L	R	R	R	L	L	L	L	L	L	L	R	L	R	R	L	L	R	L	NP
Scomber scombrus	**Atlantic mackerel**	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	M	M	H	R	L	NP	L	R	NP
Raja ocelleta	Winter skate	NP	R	R	R	R	R	L	L	L	L	L	L	R	L	L	R	L	L	L	R	R	R
Acipenser oxyrinchus	Atlantic sturgeon	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	R	NP	NP	R	R	R	R	NP	R	R	R	NP
Peprilus triacanthus	Butterfish	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	R	NP	R	R	R	NP	R	NP	L	R	NP	M
Squalus acanthias	Spiny dogfish	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	R	R	NP	NP	NP	NP
Lophius americanus	Monkfish	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP
Tautogolabrus adspersus	Cunner	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP
Pomatomus saltatrix	Bluefish	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP
Morone Americana	White perch	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP
Pollachius virens	Pollock	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP
Urophycis chuss	Red hake	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP
Merluccius bilinearis	Silver hake	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	L	R	NP	NP	L	NP	R	NP	R	NP	NP	NP
Myoxocephalus octodecemspinosus	Longhorn sculpin	NP	NP	R	R	NP	NP	R	R	R	R	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Hemitripterus americanus	Sea raven	R	R	R	R	NP	NP	R	NP	R	R	NP	R	NP	NP	NP	NP	R	NP	NP	NP	R	NP

NP- Not present in catch
R - Rare (<10)
L - Present in low abundance (10-50)
M - Present in moderate abundance (50-500)
H - Present in high abundance (>500)

Table 5: The presence and relative abundance of identified species captured at the Five Islands site throughout the study. Fishes that were common are highlighted in bold and their seasonal abundances are plotted in Figure 11 – 21.

Scientific Name	Common Name	Relative Abundance Date (2013)																			
		May 2	May 7	May 16	May 17	May 22	May 23	May 30	June 5	June 6	June 14	June 20	June 21	June 25	June 26	July 3	July 9	July 17	July 24	July 31	Aug. 9
Alosa pseudoharengus	**Alewife**	M	M	M	M	M	R	M	L	M	M	M	M	H	H	L	M	M	L	L	R
Alosa sapidissima	**American shad**	L	L	M	L	L	NP	M	L	L	M	M	M	H	M	L	M	NP	NP	R	NP
Alosa aestivalis	**Blueback herring**	NP	R	L	NP	L	NP	NP	R	L	H	H	H	H	H	L	L	M	R	L	NP
Clupea harengus	**Atlantic herring**	L	R	L	L	H	M	M	R	NP	NP	H	H	NP	NP	H	NP	H	H	H	H
Pseudopleuronectes americanus	**Winter flounder**	L	L	L	NP	L	L	L	M	L	L	M	M	M	M	L	L	L	L	L	L
Osmerus mordax	**Rainbow smelt**	NP	M	L	L	L	L	M	L	L	L	M	M	M	M	L	L	NP	L	L	M
Scophthalmus aquosus	Windowpane	R	NP	R	R	NP	NP	R	R	NP	R	NP	R	R	R	R	R	R	R	R	NP
Morone saxatilis	Striped bass	NP	R	L	L	M	L	L	R	R	R	R	R	R	NP	NP	NP	NP	NP	NP	NP
Scomber scombrus	**Atlantic mackerel**	NP	NP	NP	NP	R	NP	NP	R	NP	NP	H	R	R	NP	M	R	R	NP	R	NP
Peprilus triacanthus	Butterfish	NP	NP	NP	NP	NP	NP	NP	R	R	NP	L	R	NP	NP	NP	NP	NP	NP	R	R
Hemitripterus americanus	Sea raven	NP	NP	NP	R	NP	R	R	R	NP	R	R	NP	NP	NP	NP	NP	NP	NP	NP	NP
Myoxocephalus octodecemspinosus	Longhorn sculpin	R	NP	R	R	NP	R	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
Acipenser oxyrinchus	Atlantic sturgeon	NP	NP	NP	R	NP	R	NP	NP	NP	NP	R	R	NP	NP	NP	NP	NP	NP	NP	NP
Liopsetta putnami	Smooth flounder	NP	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R
Raja ocellata	Winter skate	NP	R	R	R	R	R	NP	R	R	R	NP	NP	NP	NP	NP	NP	NP	R	NP	NP
Microgadus tomcod	Atlantic tomcod	NP	R	NP	NP	NP	R	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	R	R
Urophycis chuss	Red hake	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP
Merluccius bilinearis	Silver hake	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP	NP
Squalus acanthias	Spiny dogfish	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP	NP	NP	NP	NP
Syngnathus fuscus	Northern pipefish	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	R	NP	NP
Salvelinus fontinalis	Brown trout	NP	R	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP	NP	NP	NP
Pollachius virens	Pollock	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	R	NP	NP

NP- Not present in catch
R - Rare (<10)
L - Present in low abundance (10-50)
M - Present in moderate abundance (50-500)
H - Present in high abundance (>500)

Table 6: Linear length-weight regression equations and coefficient of determination values (R^2) for species represented in large numbers in weirs at Bramber and Five Islands.

Common Name	**Bramber Weir**		**Five Islands Weir**	
	Linear Regression	**R^2**	**Linear Regression**	**R^2**
Alewife	y = -5.54 + 3.23x	0.957	y = -5.97 + 3.36x	0.951
Blueback Herring	y = -4.87 + 2.97x	0.946	y = -4.83 + 2.96x	0.908
American Shad	y = -5.76 + 3.26x	0.991	y = -5.96 + 3.32x	0.985
Atlantic Herring	y = -7.09 + 3.66x	0.907	y = -4.78 + 2.92x	0.973
Atlantic Mackerel	y = -5.23 + 3.08x	0.834	y = -6.59 + 3.48x	0.849
Rainbow Smelt	y = -5.01 +2.93x	0.939	y = -5.35 + 3.04x	0.884
Atlantic Tomcod	y = -4.85 + 2.96x	0.872	NA	NA
Smooth Flounder	y = -3.74 + 2.81x	0.902	NA	NA
Winter Flounder	y = -4.51 + 3.01x	0.982	y = -4.16 + 2.92x	0.911
Windowpane	y = -4.80 + 3.08x	0.965	NA	NA
Striped Bass	y = -4.97 + 3.10x	0.986	y = -4.92 + 2.95x	0.857
Atlantic Sturgeon	NA	NA	NA	NA

Table 7: General observations on abundance and size frequency for common fishes captured (see Figures 11-33).

Species	Bramber	Five Islands
Alewife	• Spawners captured in mid-April, early May • High abundance in late June • Decrease in frequency of large Alewife over the season	• High abundance in late June followed by very low abundance in July • Decrease in Alewife size over the sampling season
Blueback Herring	• Appeared in high abundance in mid-May, following absence in April • Consistently appeared in catches from May-August	• High abundance in late June, similar to Alewife • Abrupt decrease in abundance in July, similar to Alewife
American Shad	• Peaks in abundance in April and June; low in May, July & Aug; • Adult fish (>45 cm) only in April • Juveniles and adults from May-August	• General increase in abundance from early May to late June • Juveniles and adults from May-August
Atlantic Herring	• Spawning fish captured in April and May • June, July, and August captures dominated by young of the year (YOY)	• High abundance of adults in May • YOY very abundant from mid-June through to early August
Atlantic Mackerel	• Consistently low abundance aside from peak numbers in early July	• Peak capture in June, with the first appearance of YOY Atlantic Herring
Rainbow Smelt	• Consistently present in catch throughout April to mid-August • Peak abundance in August, includes adults and YOY	• Consistently present in catch (early May – early August • Appearance of YOY in late July
Atlantic Tomcod	• Adults frequent in early April and in early to mid-May • Juveniles present in low to moderate abundance from late June through early August	NA
Winter Flounder	• Gradual increase in abundance, peaking in June, followed by decrease in abundance. • Spawning fish present in April & early May • Decrease in frequency of larger fish as sampling season progresses	• Gradual increase in abundance, peaking in June, followed by decrease in abundance
Window-pane	• Present throughout April to mid-August • Peak abundance in June • Similar trend in abundance to that of Winter Flounder	NA
Smooth flounder	• Abundance pattern similar to other flounders • High relative frequency of large founder in July	NA
Striped Bass	• Most abundant in May, captured throughout study • Larger fishes captured during summer months	• Most abundant in May • Sudden absence in mid-June • Generally all similar size
Atlantic Sturgeon	• Most common during summer months	• Low abundance in mid-May to mid-June

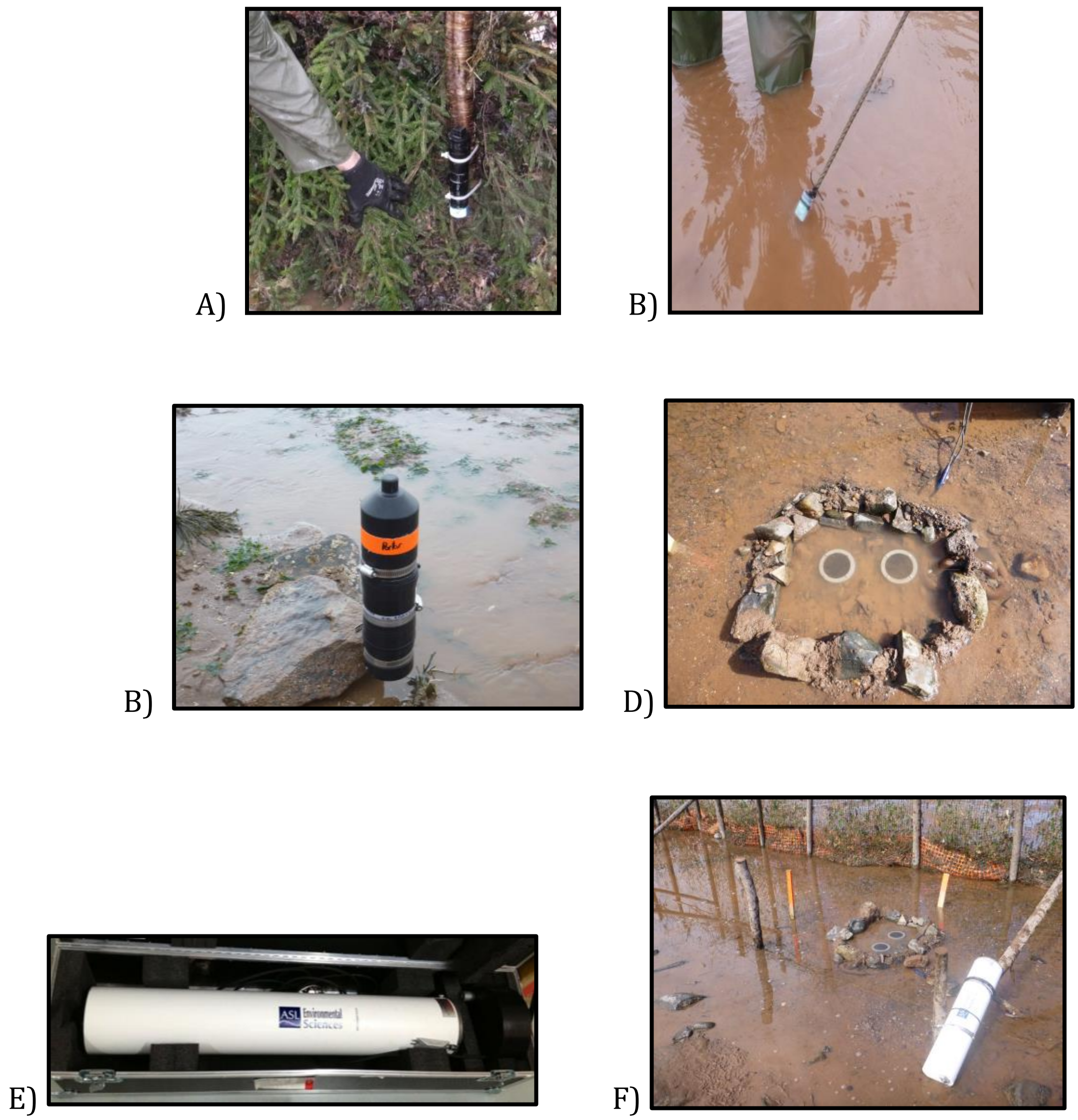


Figure 8: Images depict environmental sensors deployed at weir sites. A) A HOBO U20 Titanium Water Level Data Logger fastened to a stake at the Five Islands weir. B) A HOBO Pendant Temperature Logger attached to a support line at the Five Islands weir. C) A VEMCO VR2w acoustic receiver mounted on a rebar seaward of the Bramber weir. D) The AZFP transducer heads positioned within a small depression near the center of the long wing at the Bramber weir. E) The AZFP battery/ data storage pack. F) The positioning of the AZFP unit and battery relative to the Bramber weir structure.

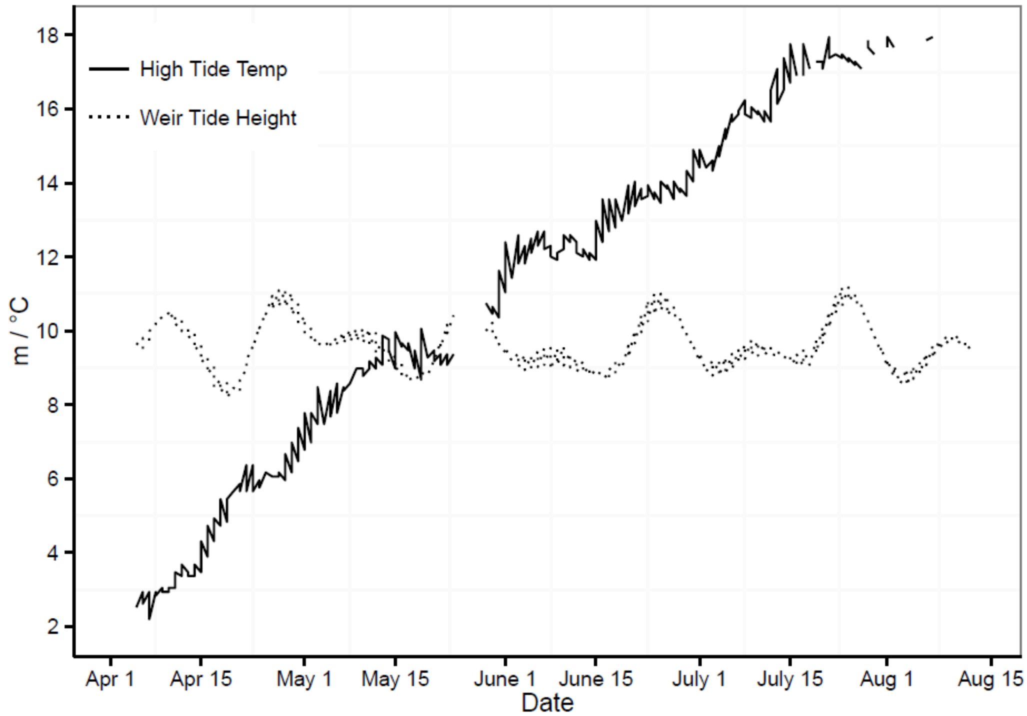


Figure 9: Water temperature at high tide (solid line) and high tide height at the weir (dotted line) in Bramber during 3 April – 12 August 2013.

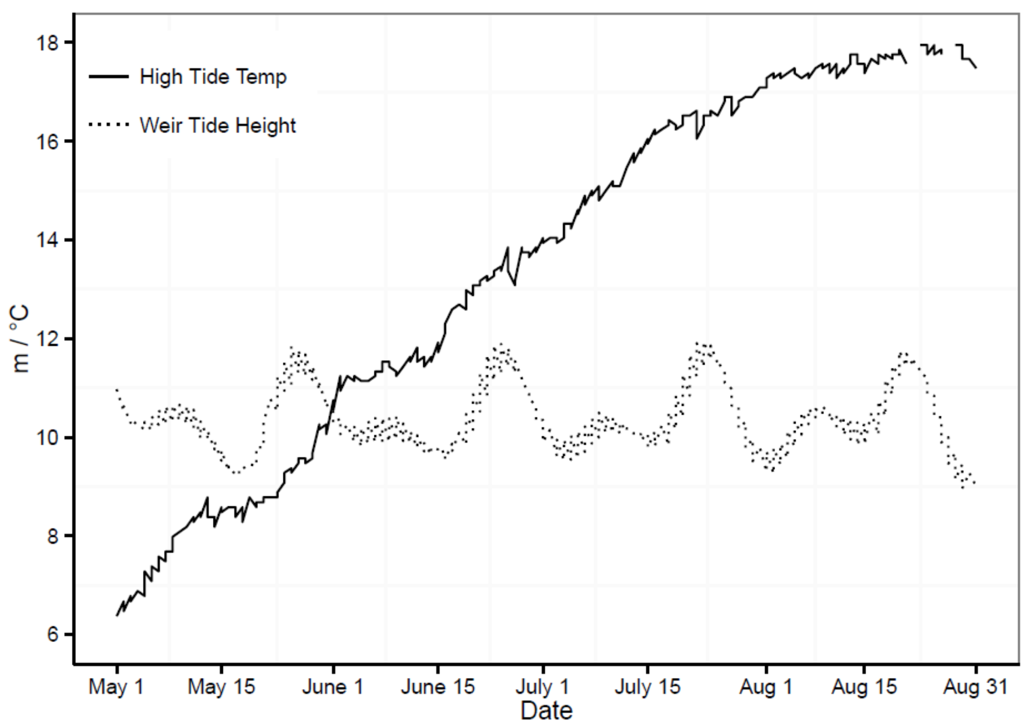


Figure 10: Water temperature at high tide (solid line) and high tide height at the weir (dotted line) in Five Islands during 1 May – 31 August 2013.

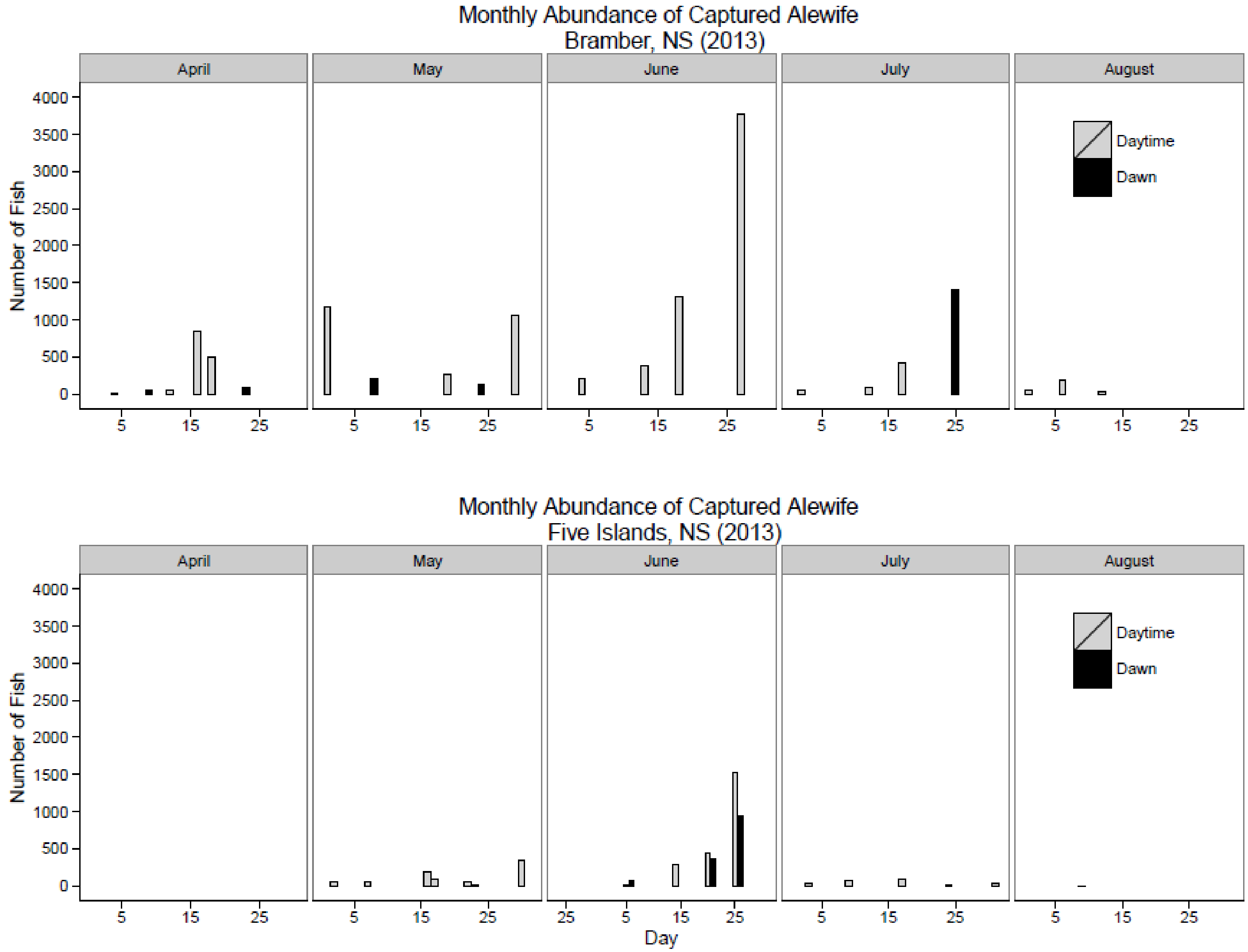


Figure 11: Total number of captured (including fish not retained by fisher) Alewife, *Alosa pseudoharengus*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

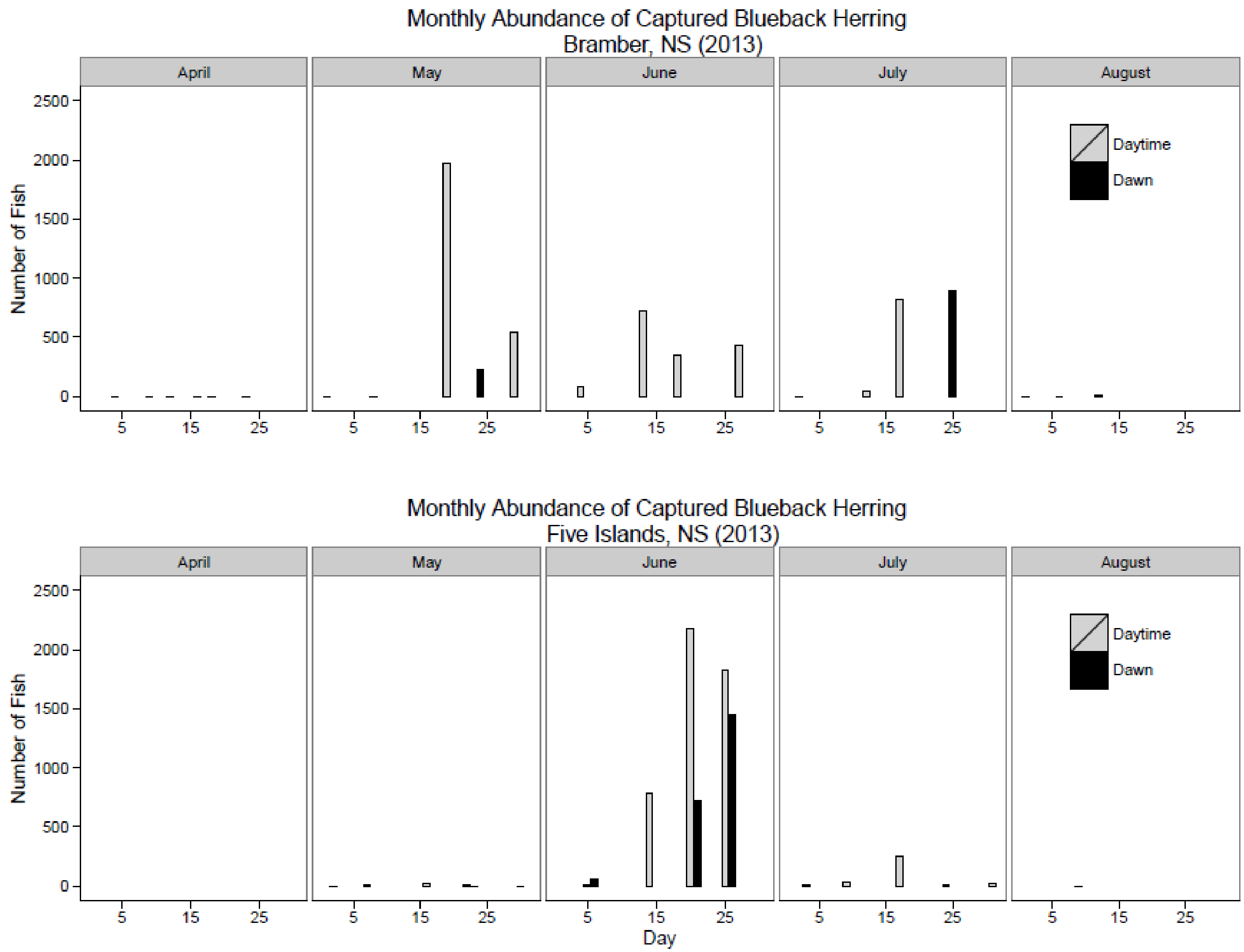


Figure 12: Total number of captured (including fish not retained by fisher) Blueback Herring, *Alosa aestivalis*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

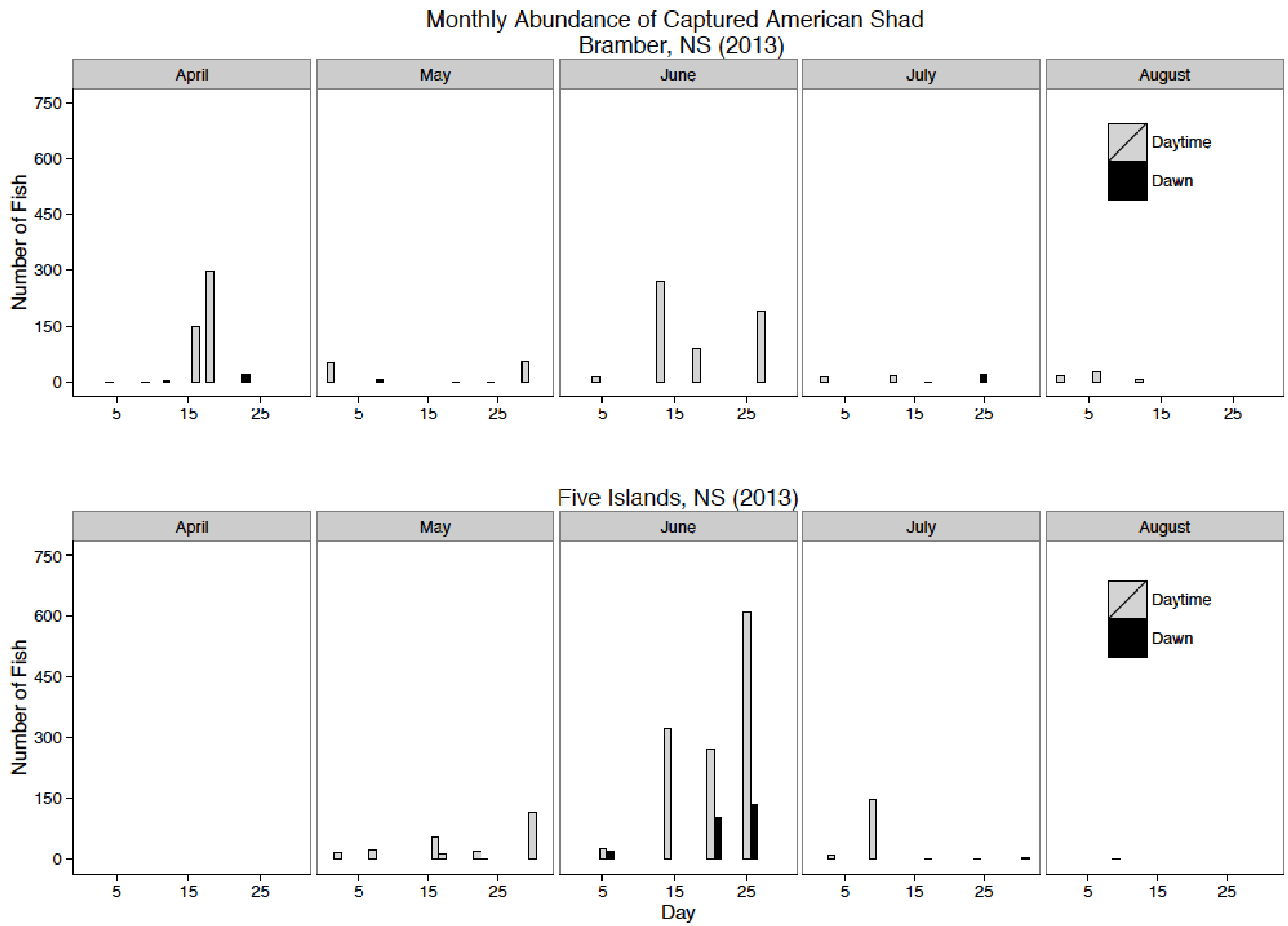


Figure 13: Total number of captured (including fish not retained by fisher) American Shad, *Alosa sapidissima*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

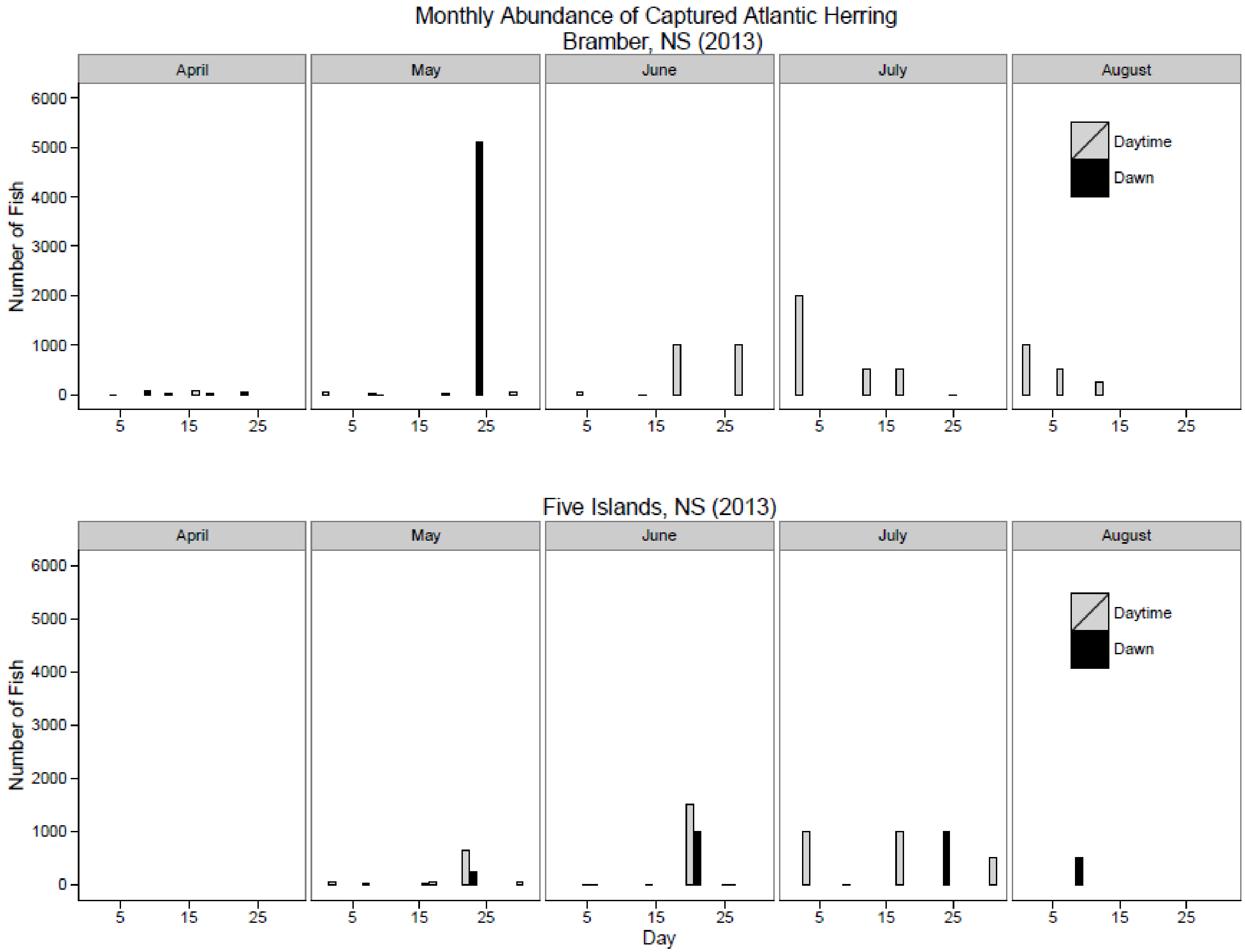


Figure 14: Total number of captured (including fish not retained by fisher) Atlantic Herring, *Clupea harengus*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

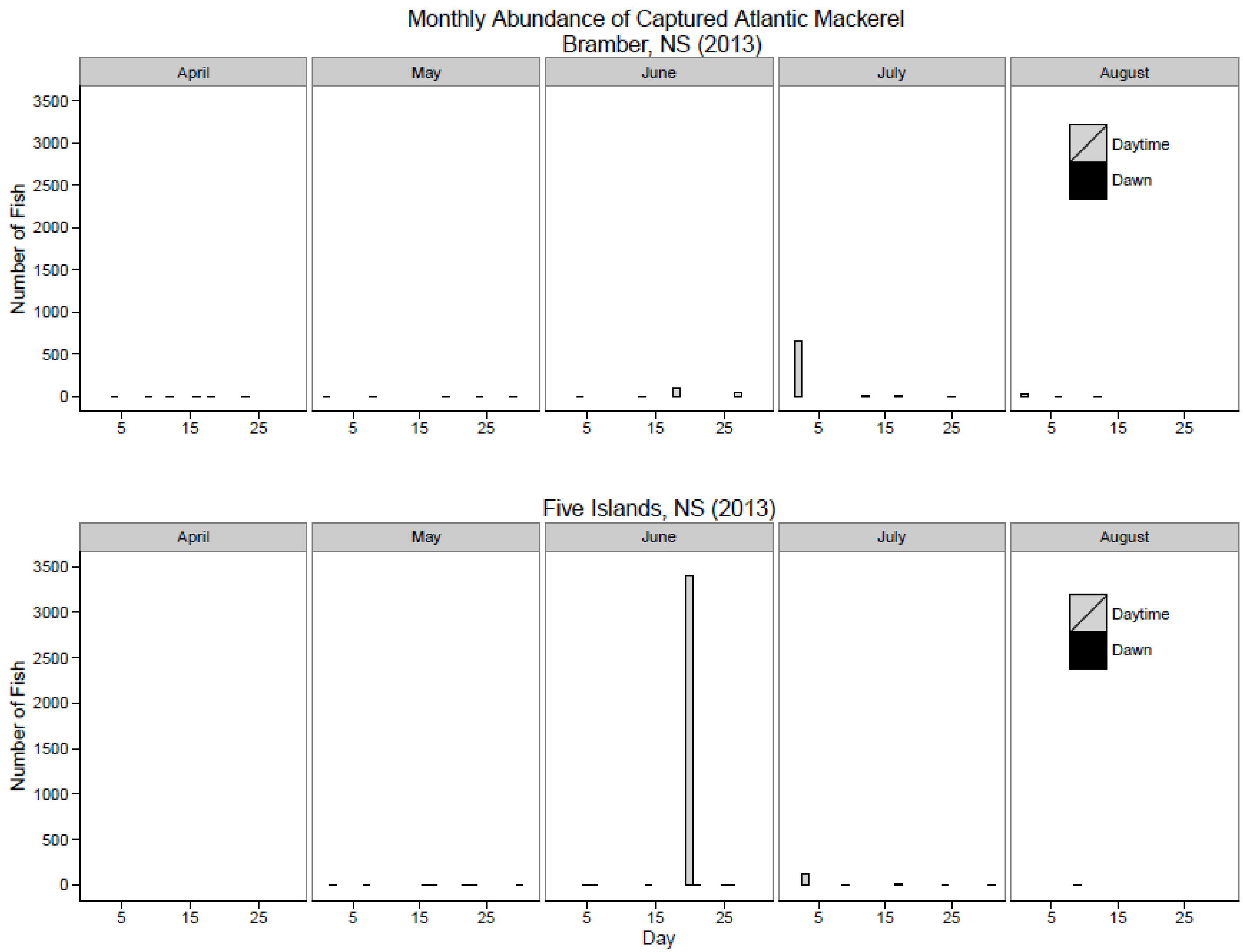


Figure 15: Total number of captured (including fish not retained by fisher) Atlantic Mackerel, *Scomber scombrus*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

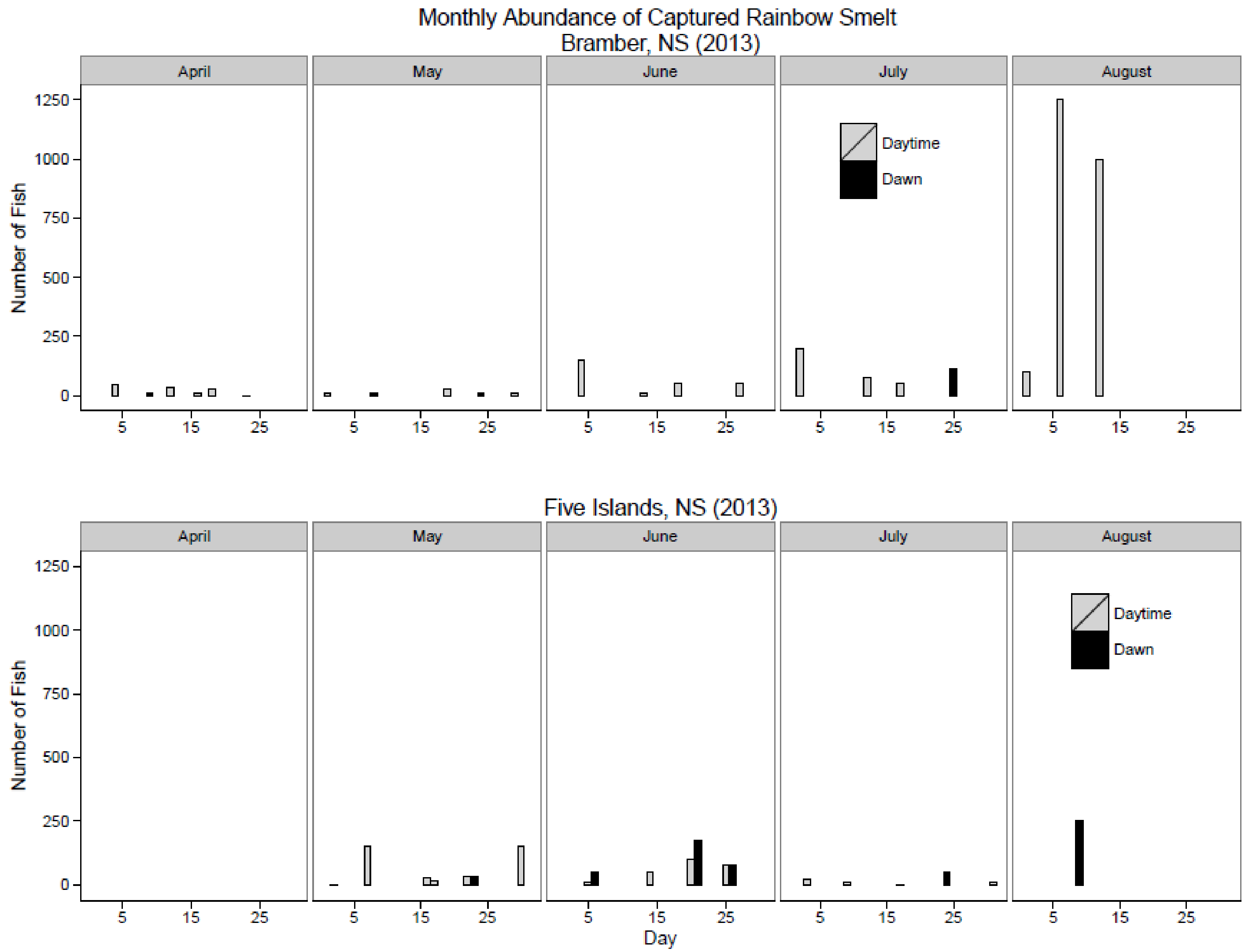


Figure 16: Total number of captured (including fish not retained by fisher) Rainbow Smelt, *Osmerus mordax*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures up to 3 hours prior to dawn.

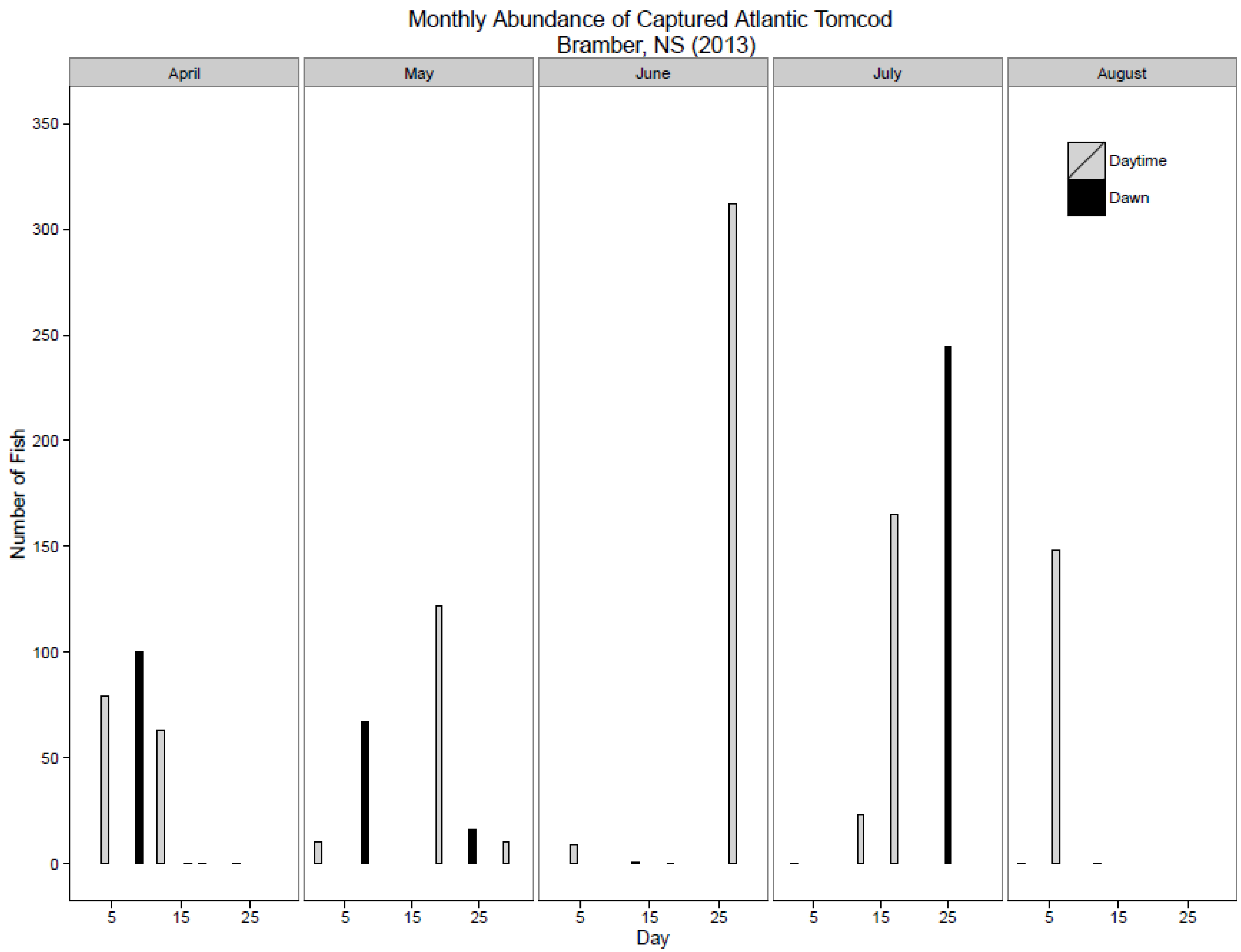


Figure 17: Total number of captured (including fish not retained by fisher) Atlantic Tomcod, *Microgadus tomcod*, on each weekly sampling event from the Bramber weir. This species was not abundant at Five Islands. Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

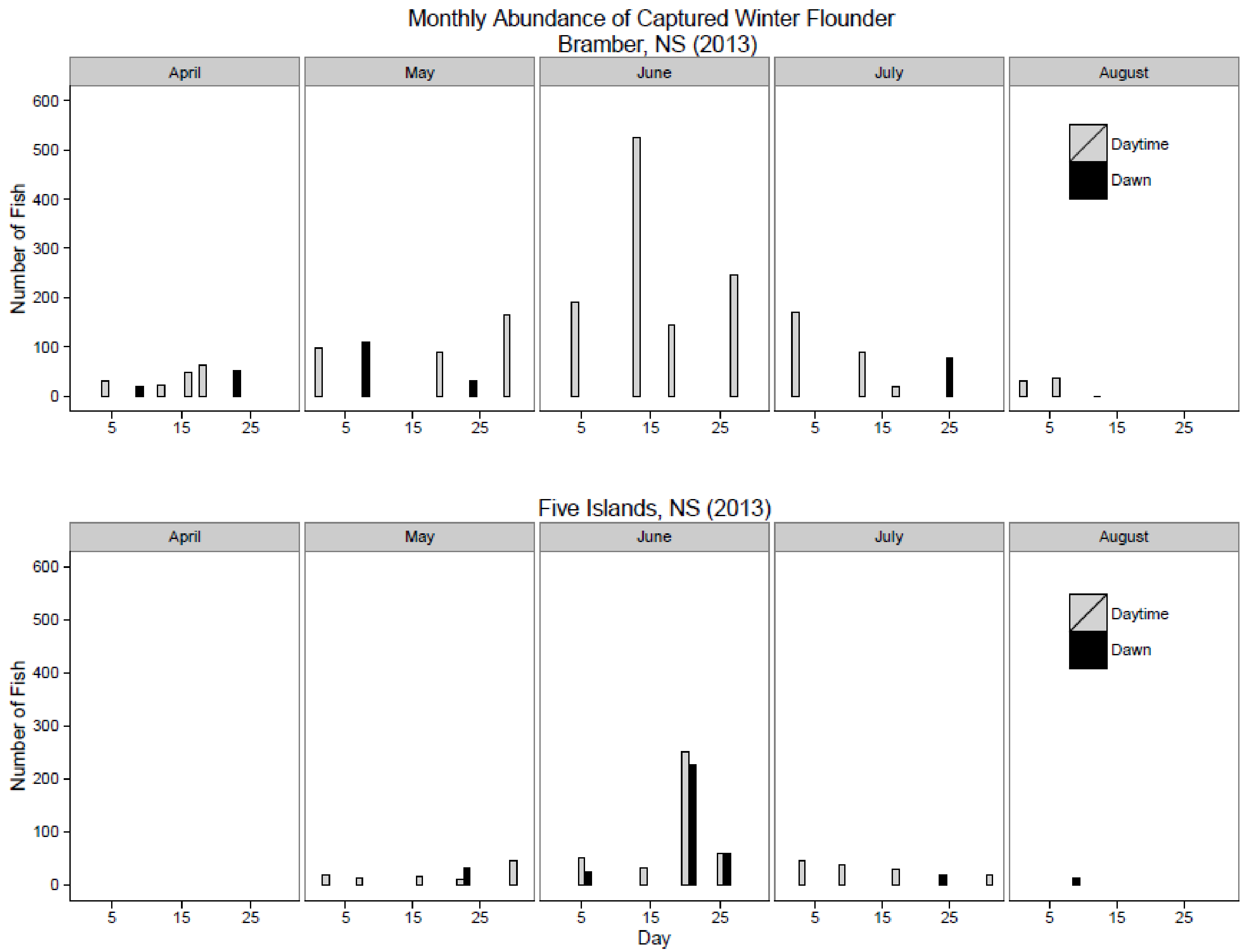


Figure 18: Total number of captured (including fish not retained by fisher) Winter Flounder, *Pseudopleuronectes americanus*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

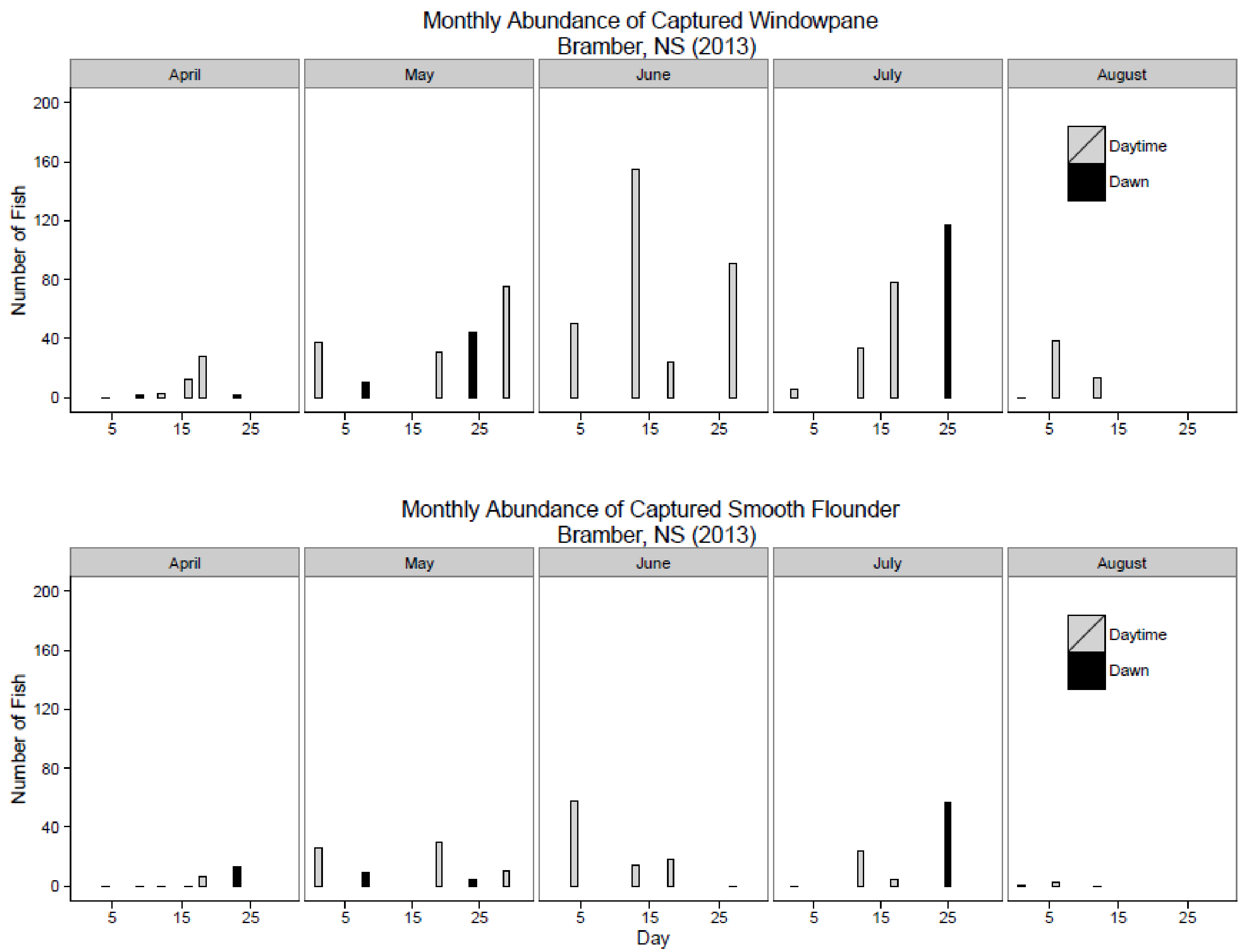


Figure 19: Total number of captured (including fish not retained by fisher) Windowpane, *Scophthalmus aquosus,* (top panel) and Smooth Flounder, *Liopsetta putnami*, (lower panel) on each weekly sampling event at the Bramber weir. These species were not abundant at Five Islands. Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

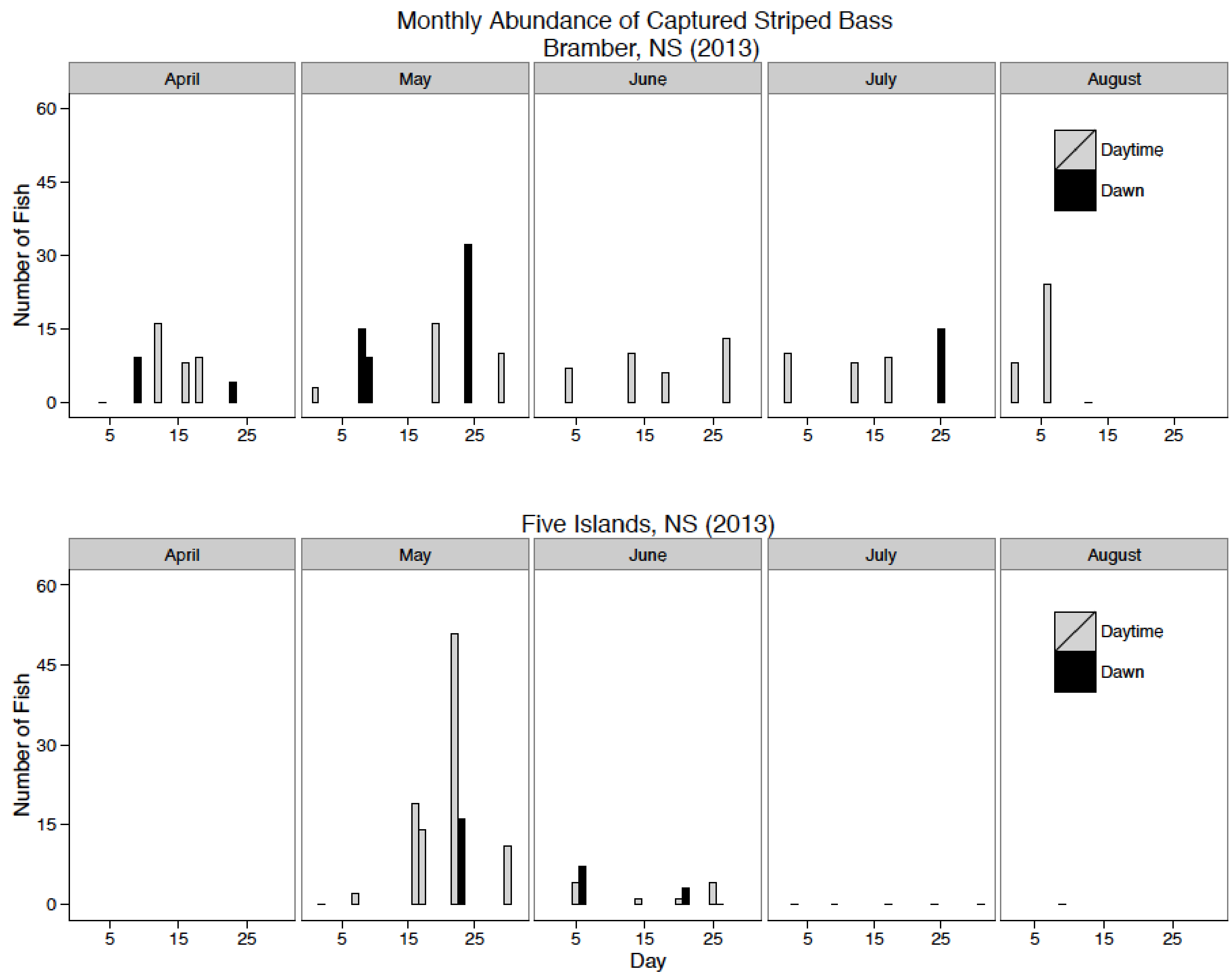


Figure 20: Total number of captured (including fish not retained by fisher) Striped Bass, *Morone saxatilis*, on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

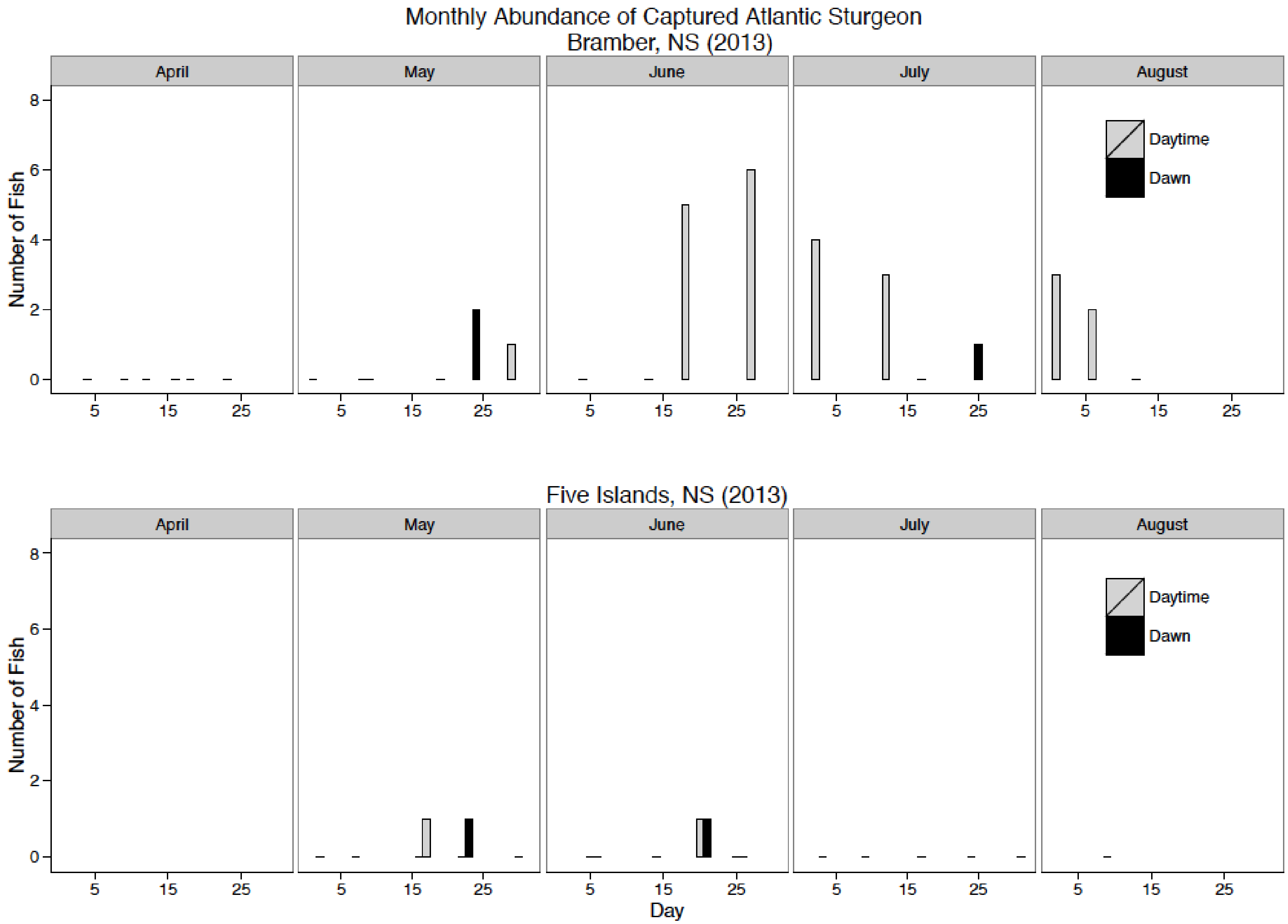


Figure 21: Total number of captured (including fish not retained by fisher) Atlantic Sturgeon, *Acipenser oxyrinchus* on each weekly sampling event from weirs at Bramber (top) and Five Islands (bottom). Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight.

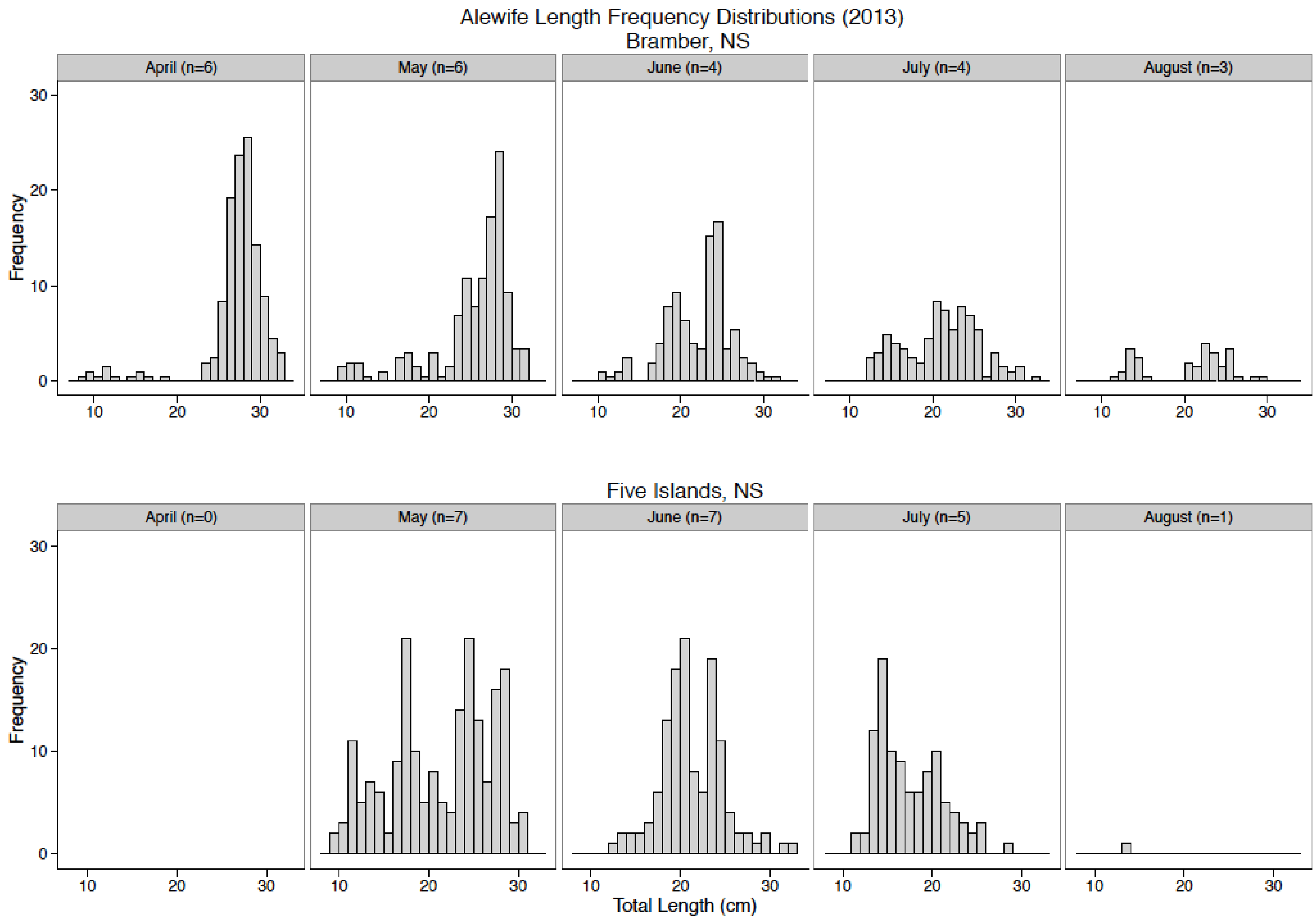


Figure 22: Total length (cm) frequency distribution by month of sampled alewife. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

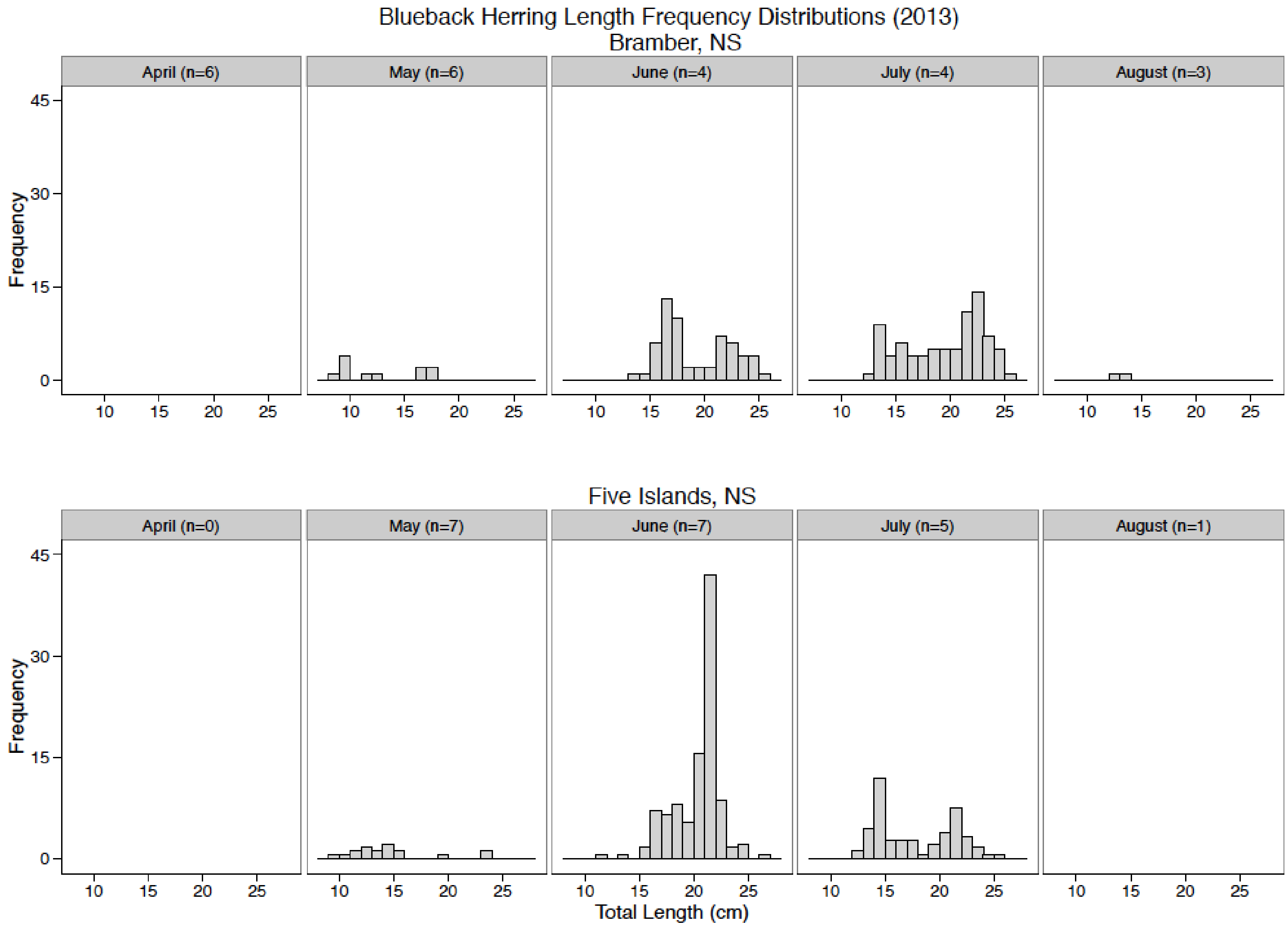


Figure 23: Total length (cm) frequency distribution by month of sampled Blueback Herring. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

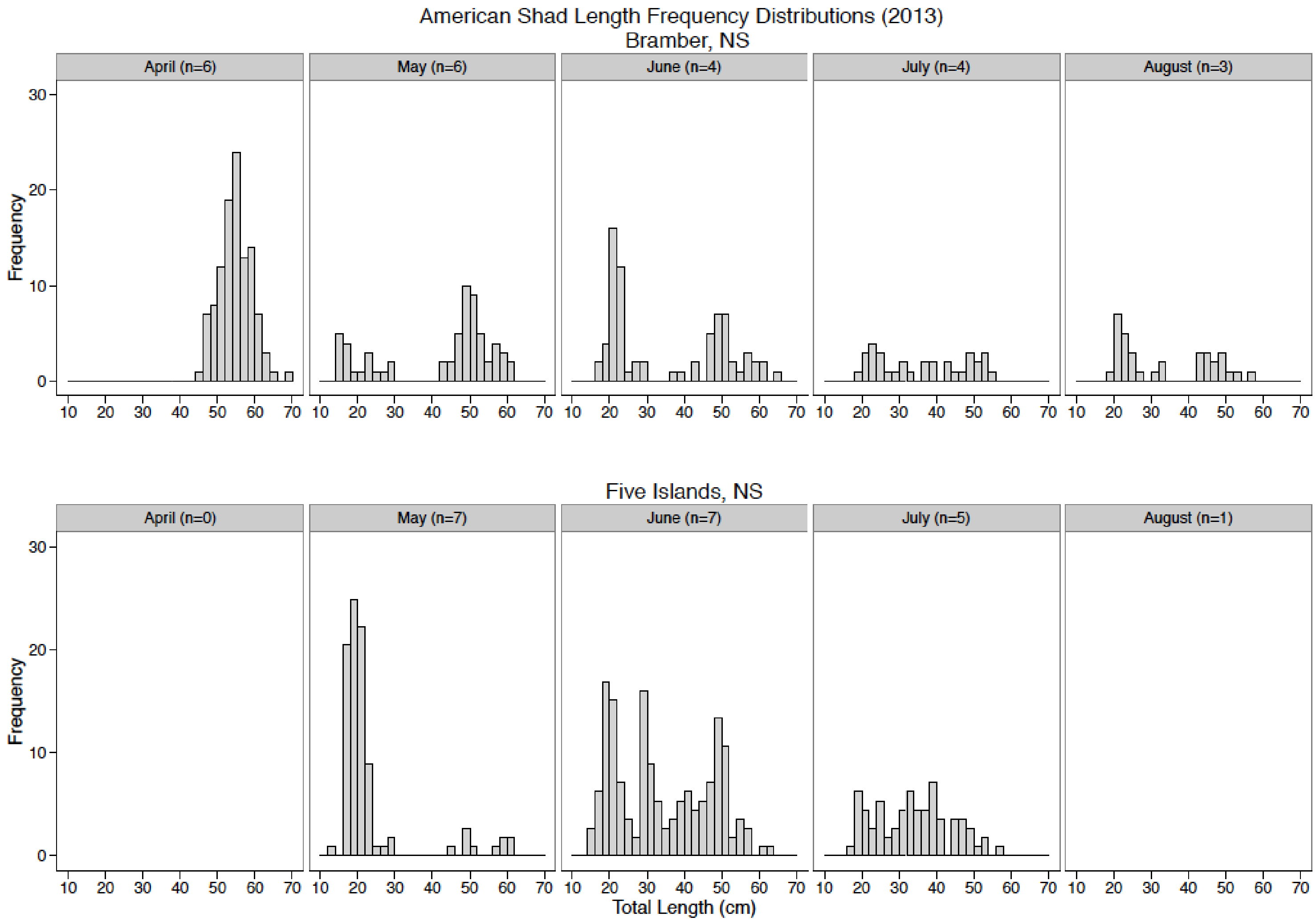


Figure 24: Total length (cm) frequency distribution by month of sampled American Shad. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

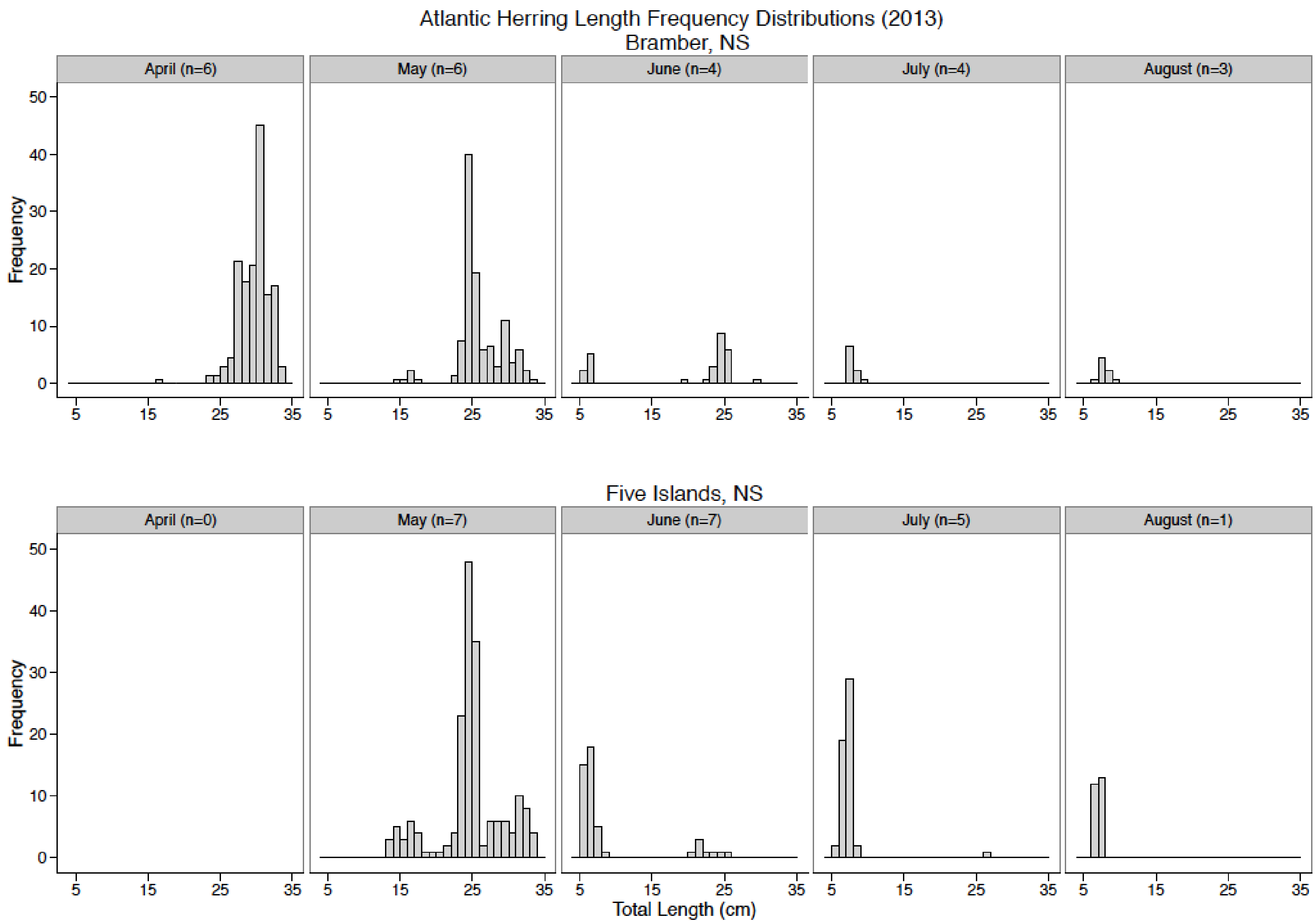


Figure 25: Total length (cm) frequency distribution by month of sampled Atlantic Herring. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

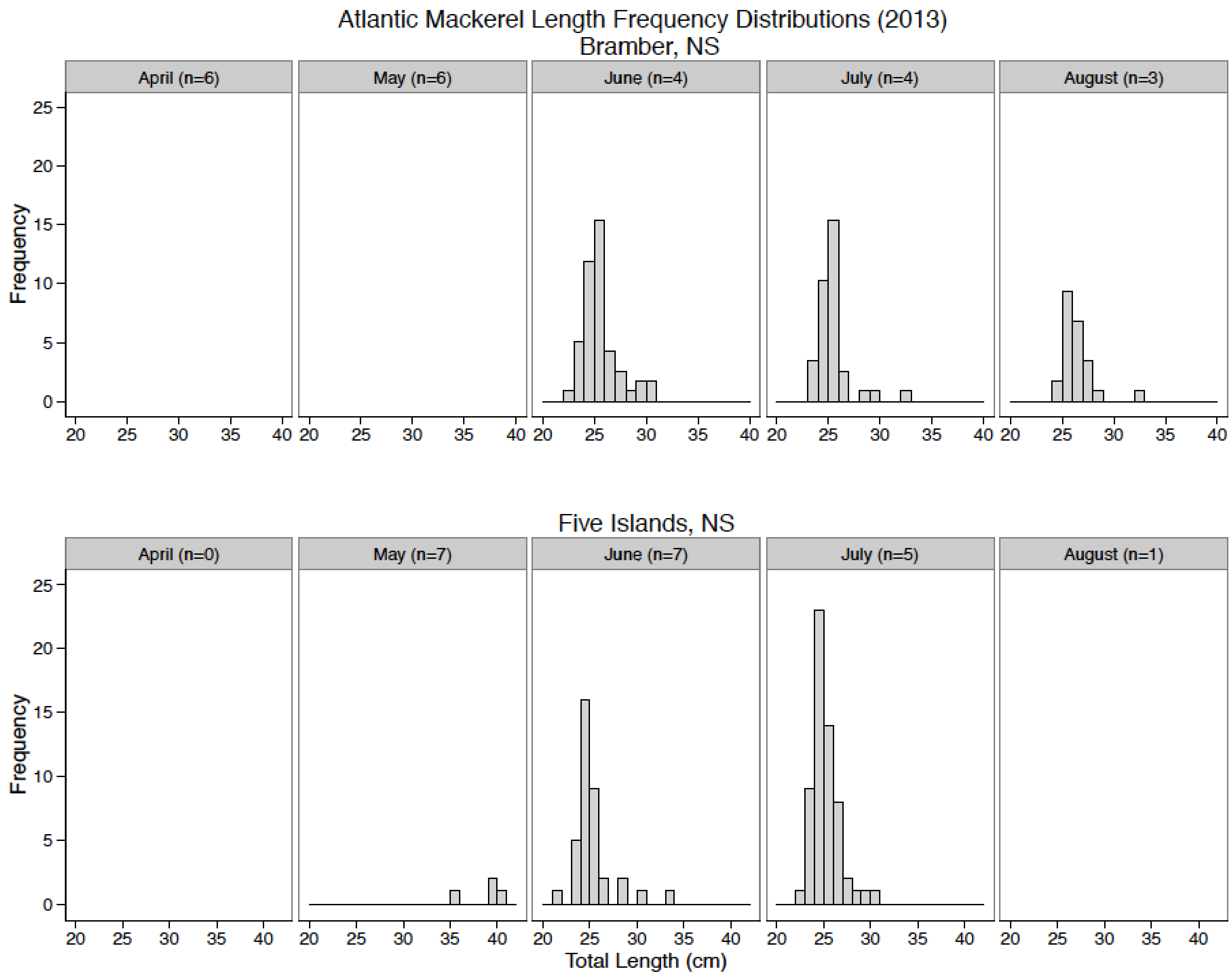


Figure 26: Total length (cm) frequency distribution by month of sampled Atlantic Mackerel. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

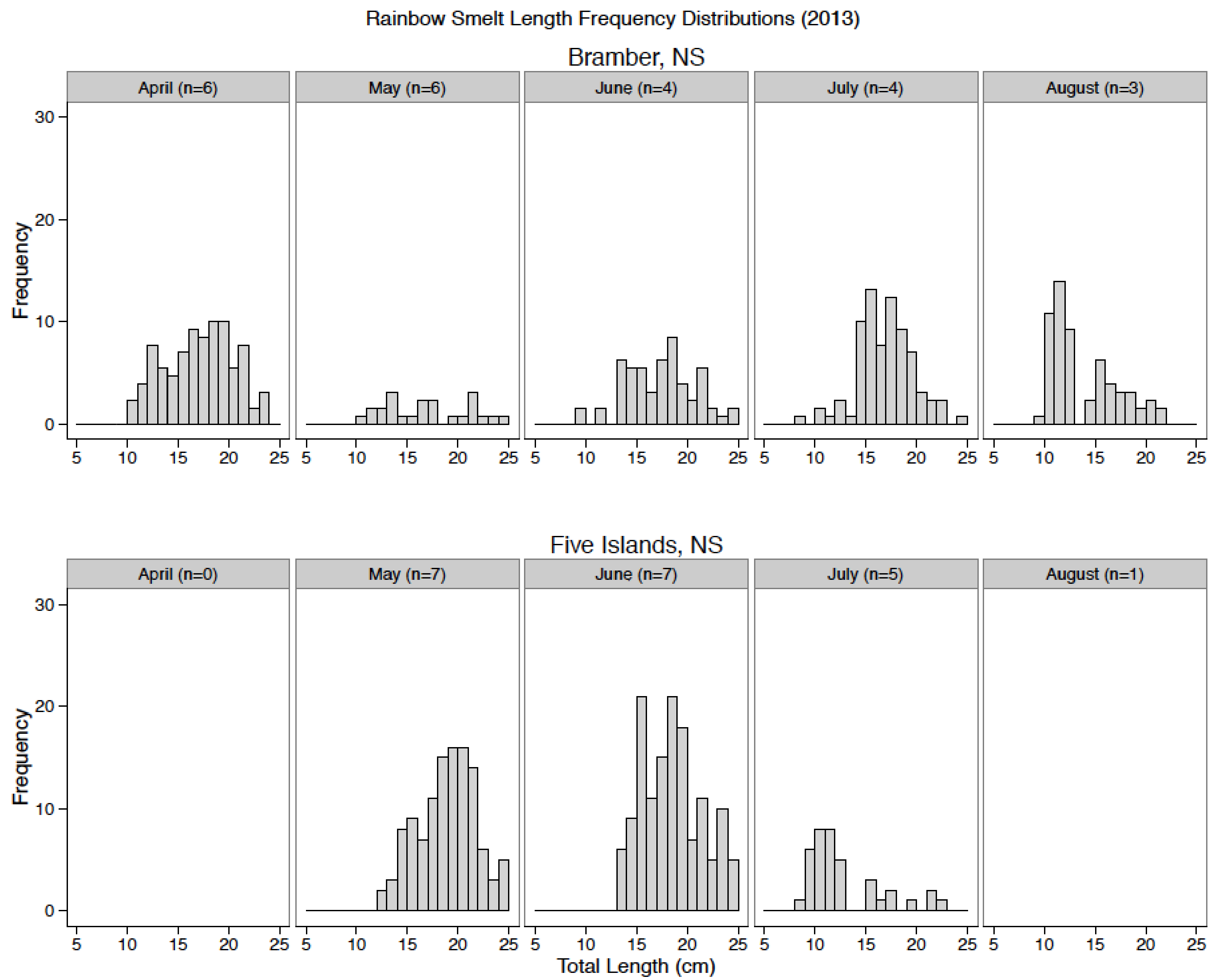


Figure 27: Total length (cm) frequency distribution by month of sampled Rainbow Smelt. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

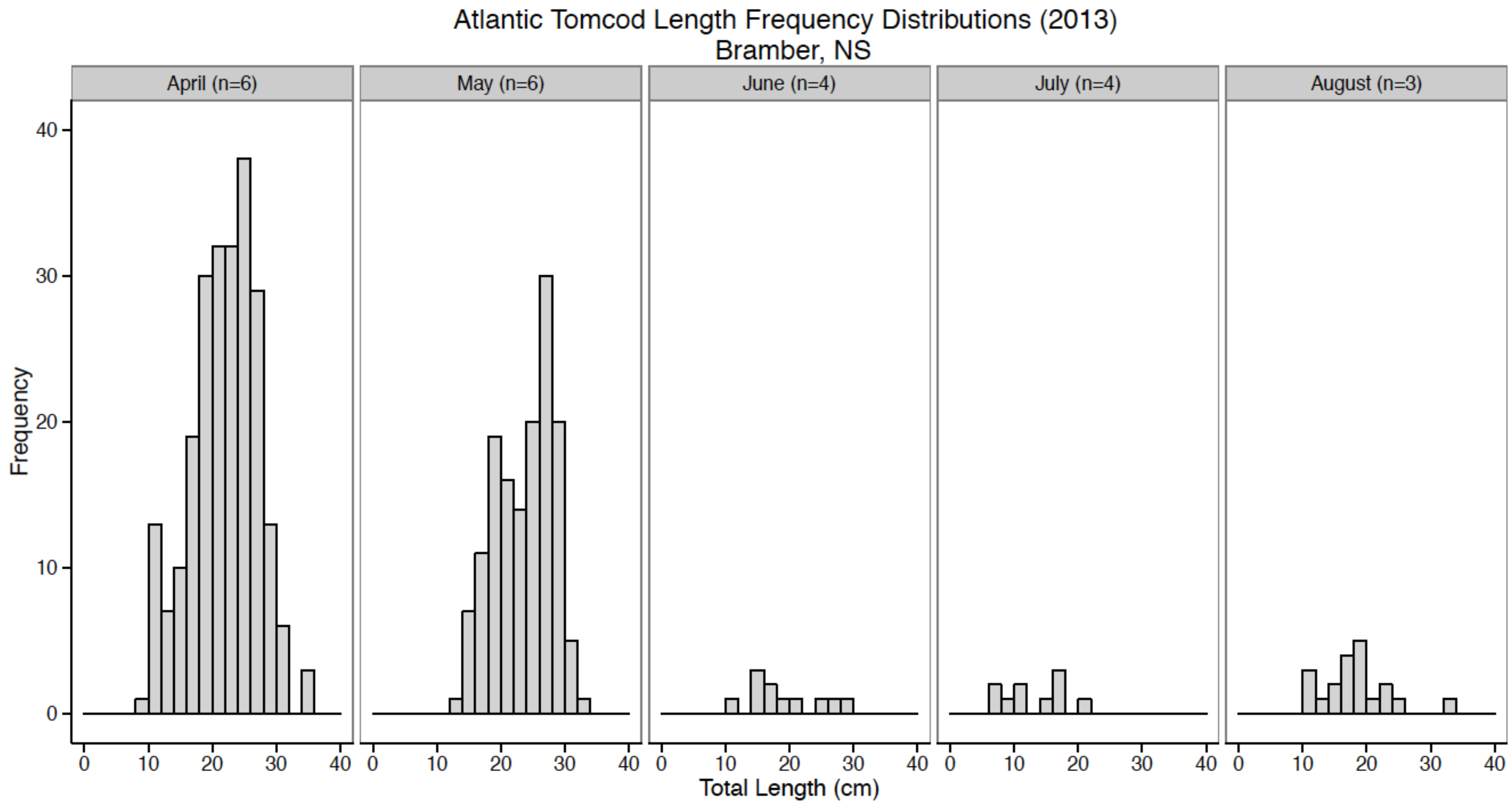


Figure 28: Total length (cm) frequency distribution by month of all sampled Atlantic Tomcod. The number of individual sampling events per month is represented by n.

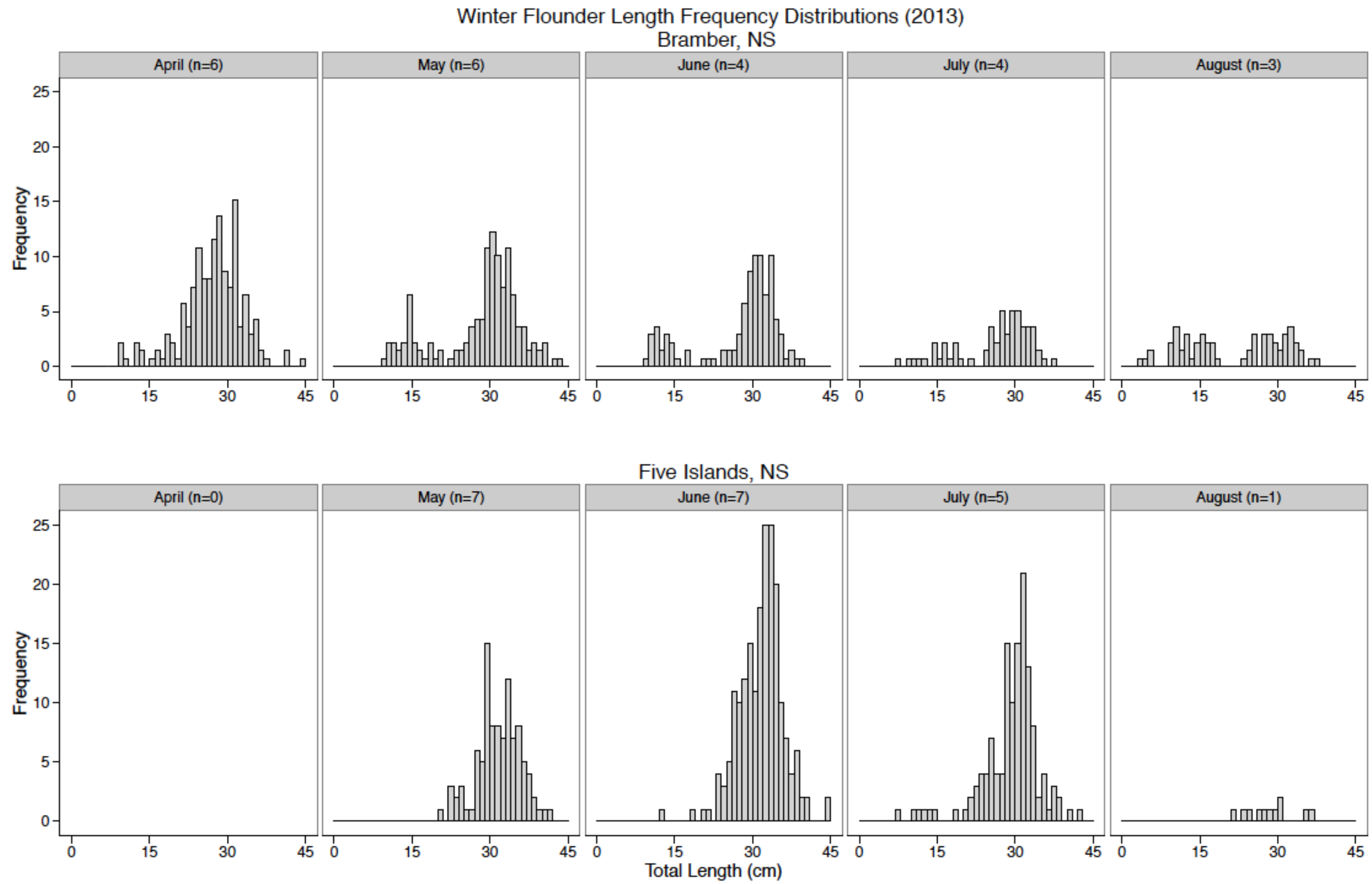


Figure 29: Total length (cm) frequency distribution by month of sampled Winter Flounder. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

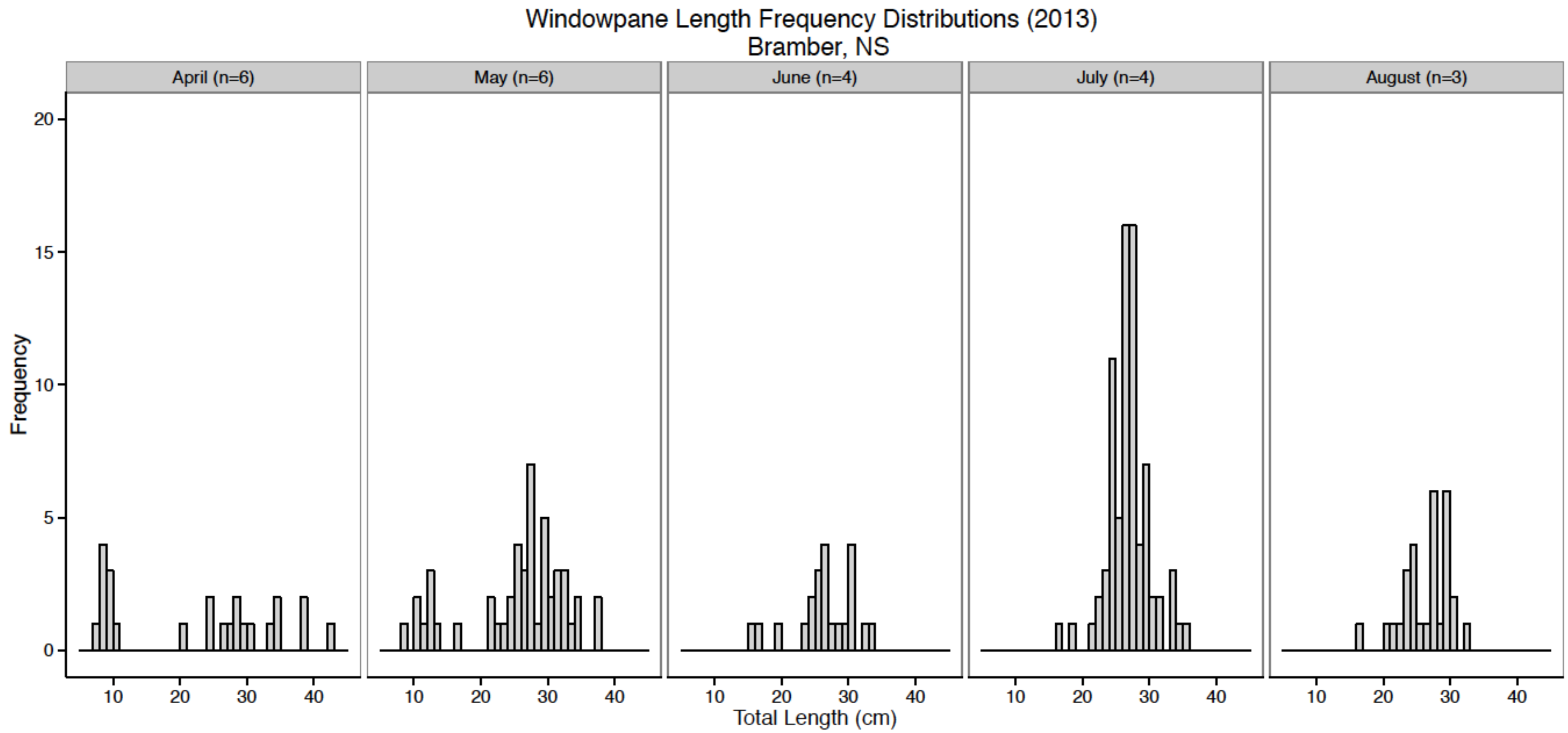


Figure 30: Total length (cm) frequency distribution by month of all sampled Windowpane at the Bramber site. The number of individual sampling events per month is represented by n.

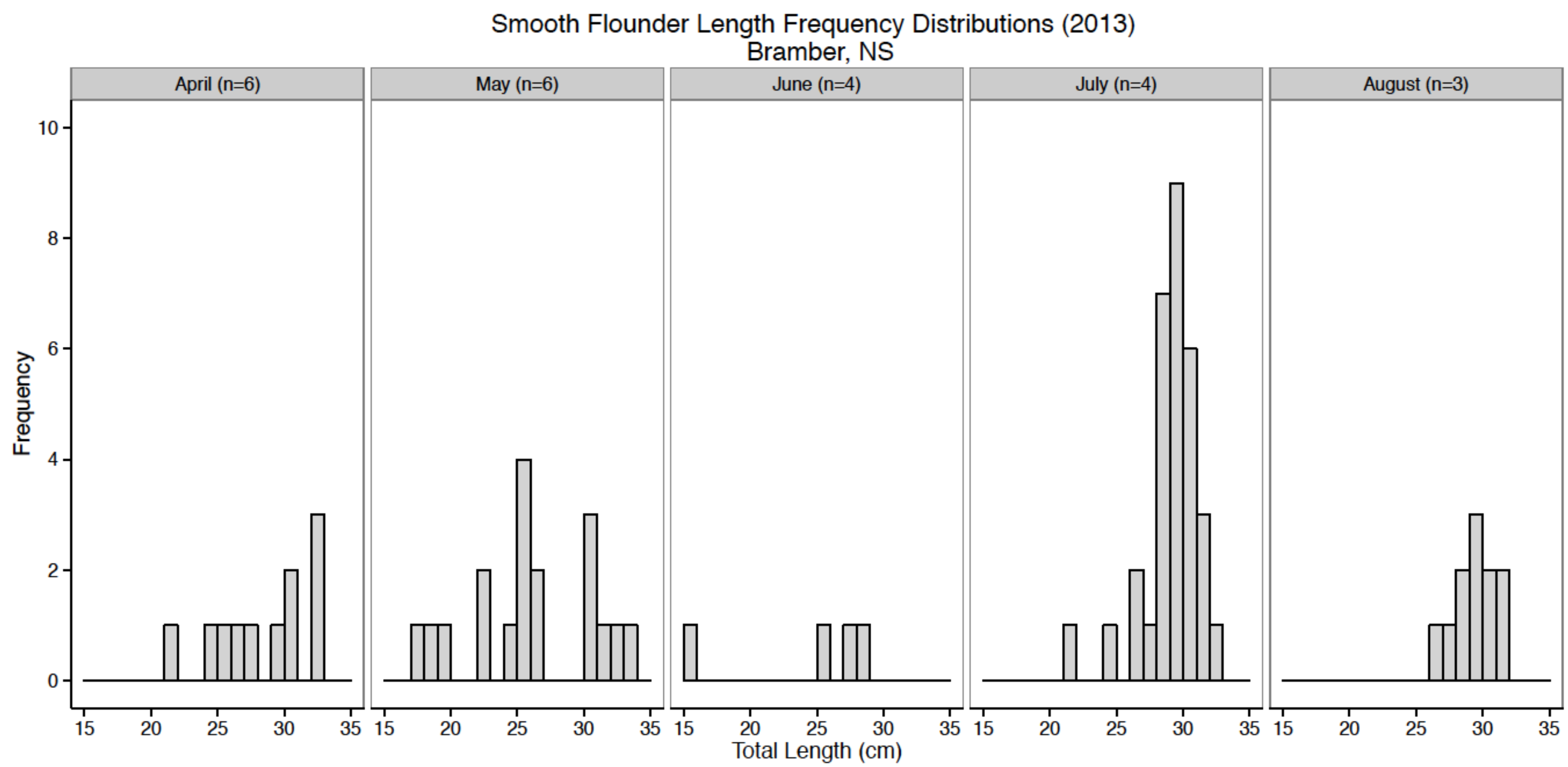


Figure 31: Total length (cm) frequency distribution by month of all sampled Smooth Flounder at the Bramber site. The number of individual sampling events per month is represented by n.

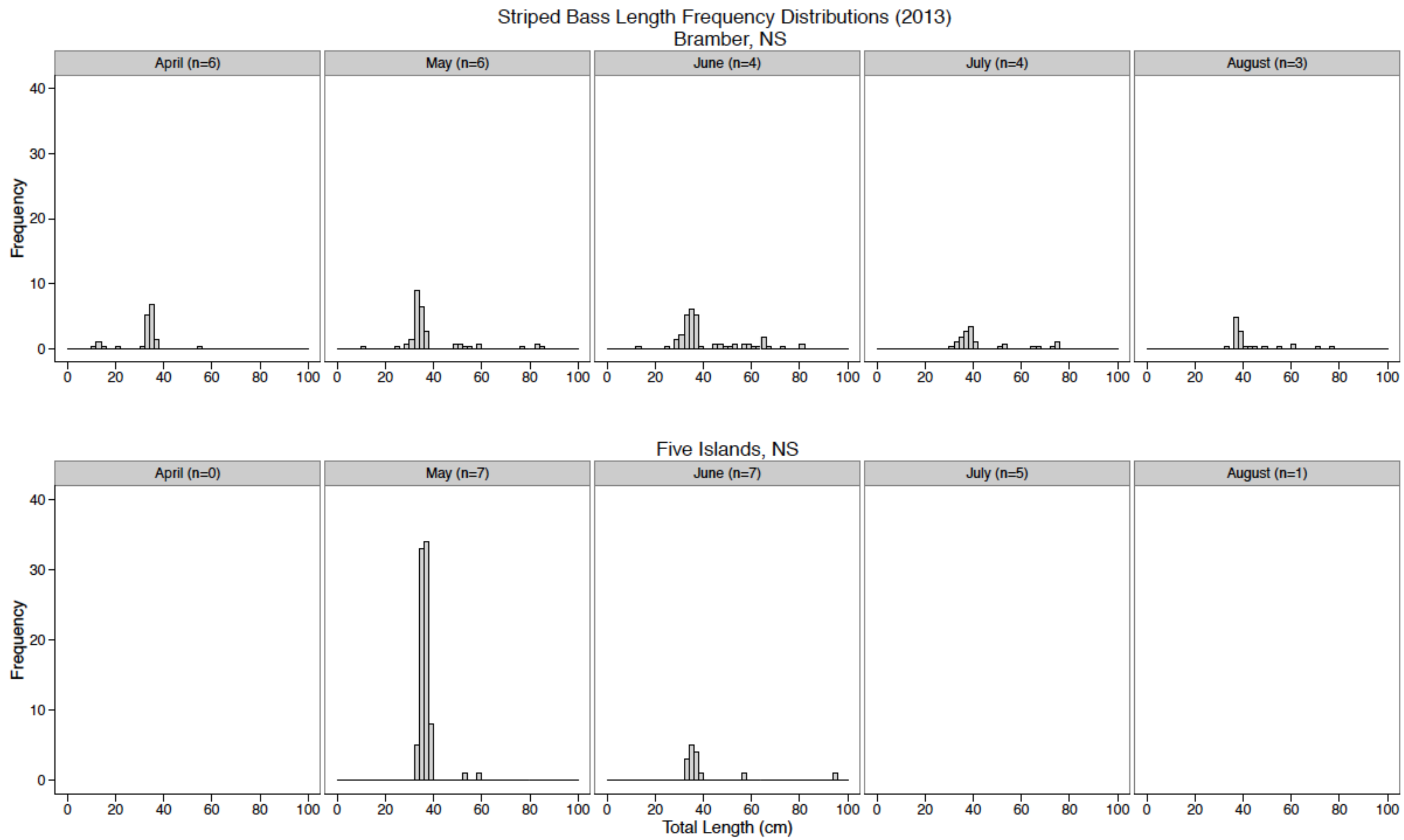


Figure 32: Total length (cm) frequency distribution by month of sampled Striped Bass. The number of individual sampling events per month is represented by n. Sample sizes have been normalized due to differences in numbers of fish sampled at each site.

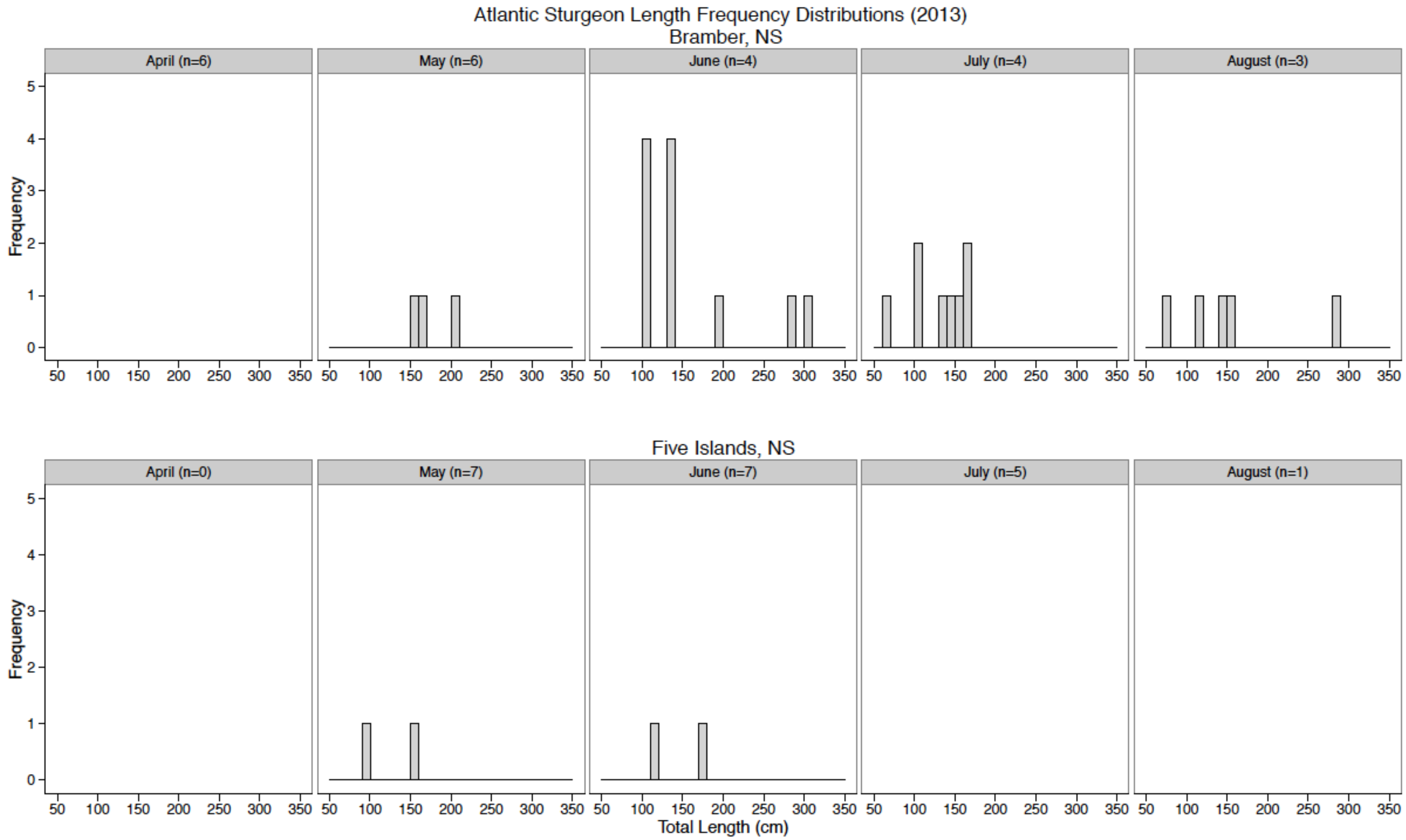


Figure 33: Total length (cm) frequency distribution by month of all sampled Atlantic Sturgeon. The number of individual sampling events per month is represented by n.

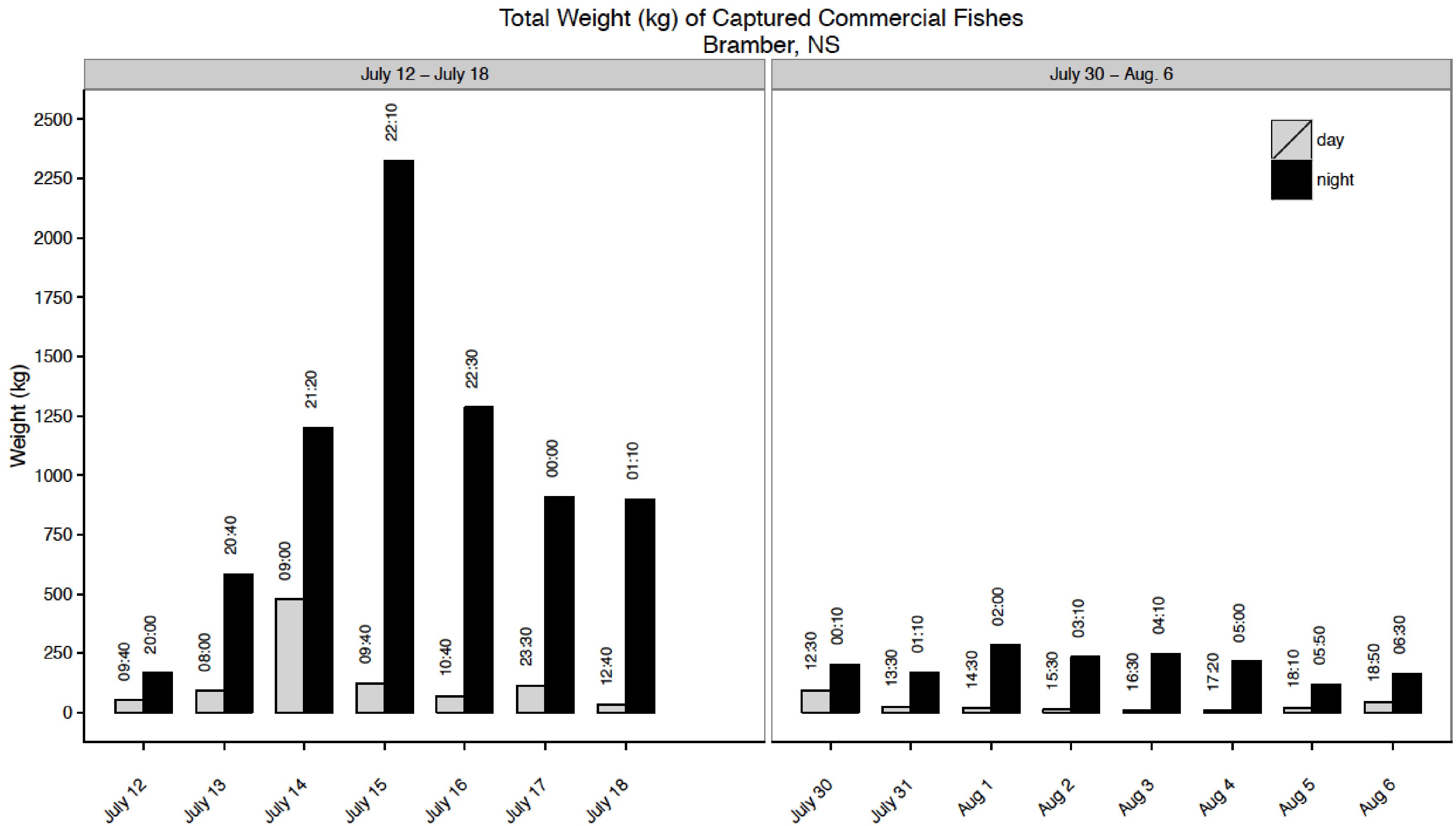
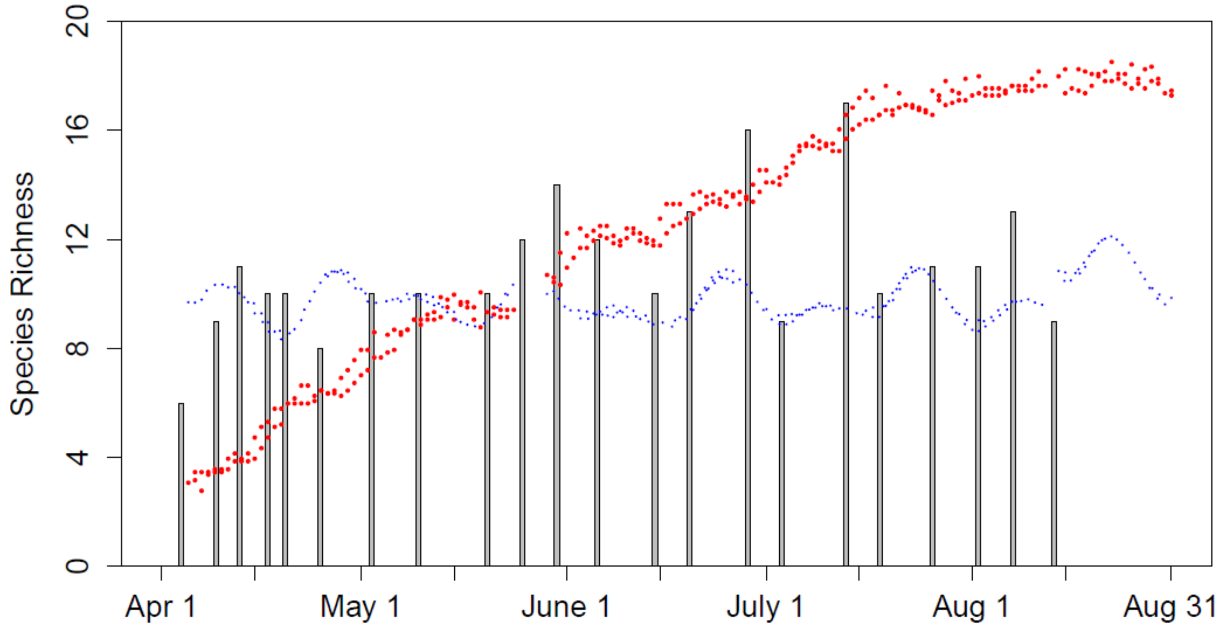


Figure 34: Day-to-day and day/night comparisons of total weight (kg) of captured (including fish not retained by fisher) commercial fishes at the Bramber site. Commercial fishes include: Gaspereau (Alewife and Blueback Herring), Flounder (Winter Flounder, Windowpane, and Smooth Flounder), and American Shad. The numbers above each bar indicate the time the weir was fishing, approximately 1-2 hours before low tide.



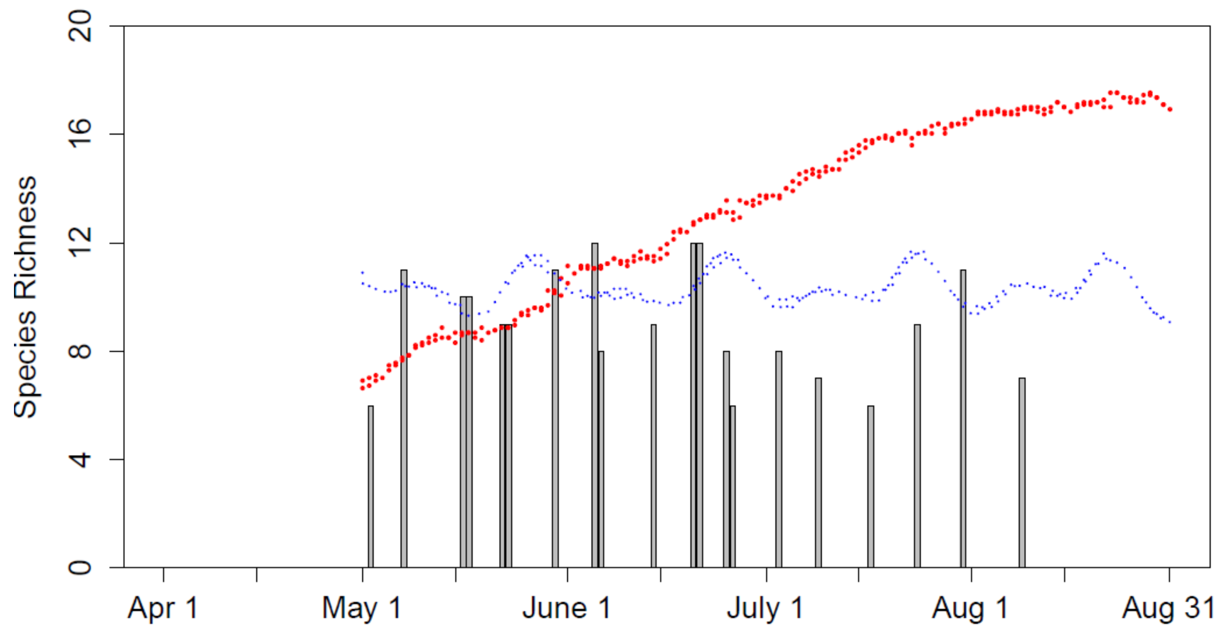


Figure 35: The number of species present on individual sampling events at the Bramber (above) and Five Islands (below) sites. The red lines indicate water temperature at high tide and the blue lines represent the water height at each weir site at the time of high tide. The positioning of the HOBO water level logger changed on the 12 August, this resulted in a slight discrepancy in the high tide height between 13 and 30 August.

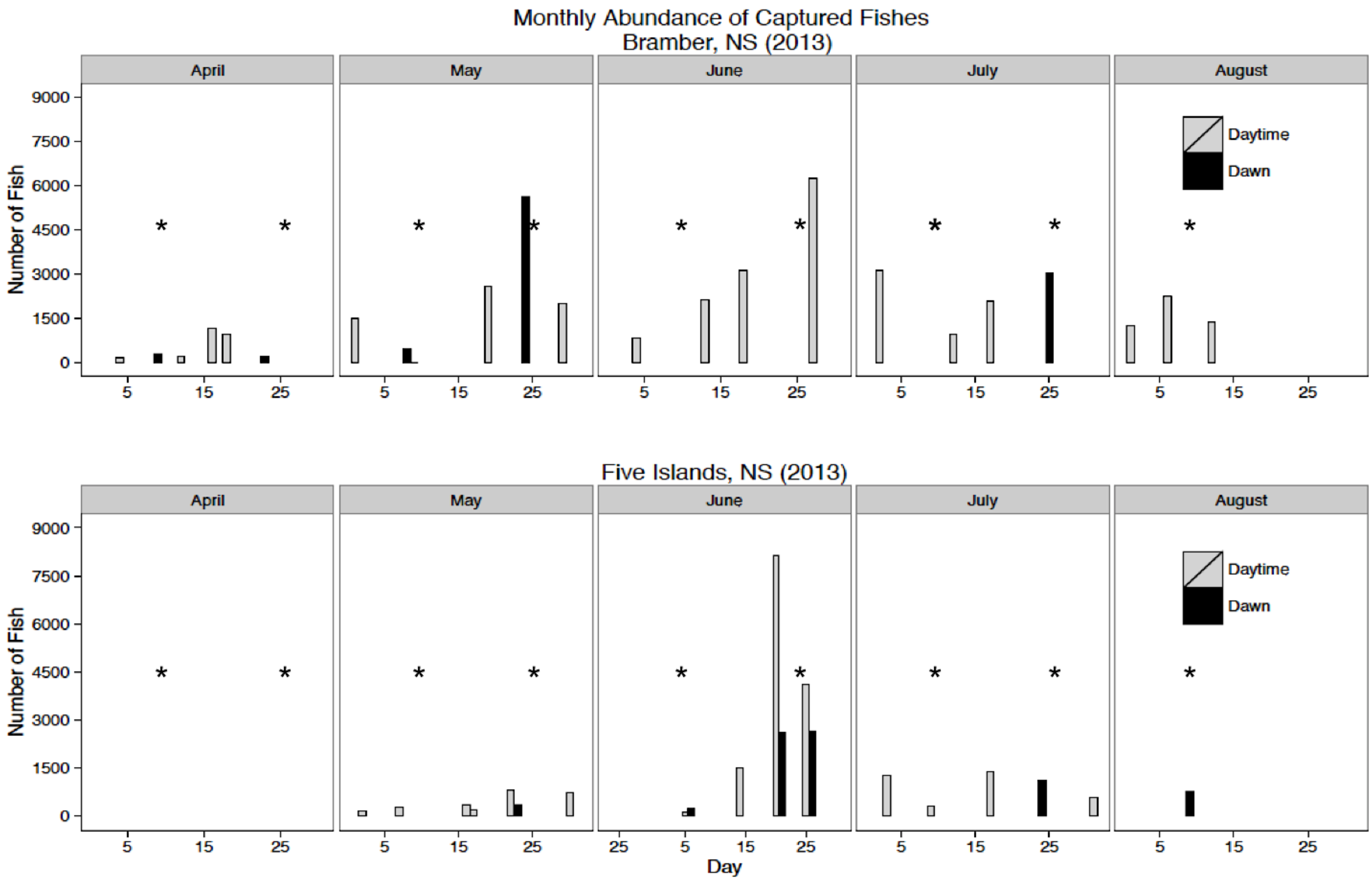


Figure 36: Total number of captured (including fish not retained by fisher) fish at Bramber (top panel) Five Island (lower panel) on each weekly sampling event. Daytime data represent fish captures following sunrise; dawn data represent fish captures during twilight. Spring tide periods when the tidal range was at it's maximum are indicated by (*).

HARBOUR PORPOISE STUDY:

Passive Acoustic Monitoring of Harbour Porpoise near Minas Basin Intertidal Weirs

Passive Acoustic Monitoring of Harbour Porpoise Near Intertidal Weirs

(for greater detail, see Reed, 2014)

General Scope

The intertidal weir study, which was focused on determining seasonal patterns in fish catches, offered a unique opportunity to examine harbour porpoise presence in the nearshore environment of Minas Basin in relation to the abundance of their prey in weir catches. This involved cetacean monitoring from the lower intertidal zone near the FORCE test area and the two intertidal weirs (Bramber and Five Island). Two passive acoustic monitoring (PAM) technologies were employed: the Porpoise Detector (C-POD; Chelonia Ltd.) and the icListenHF hydrophone (Ocean Sonics Ltd.), shown in Figure 37.

Harbour Porpoise Movements and Distribution Patterns

With a preference for temperate coastal waters (<200 m depth), harbour porpoise (*Phocoena phocoena*) typically travel in pods consisting of a few animals, however aggregations of several hundred individuals occasionally occur (Watts & Gaskin, 1985). Harbour porpoise distribution and movements are affected by biological factors (*e.g*. prey) and physical oceanographic factors (*e.g*. depth, seafloor relief, tidal currents, and sea surface temperature; Jones, 2012). Harbour porpoise prefer water temperatures in the range of 10-13.5°C (Palka, 1995) and are known to follow the movements of their preferred prey, Atlantic Herring. In the Bay of Fundy/ Gulf of Maine, the Atlantic harbour porpoise population was estimated at 89 700 individuals (Palka, 2000). Currently, there is limited data on the movement and distribution of harbour porpoise in the upper Bay of Fundy (Wood et al., 2013). Recent studies showed porpoise detections peak in Minas Passage in May and October, with lows in July and August (Tollit et al., 2011; Wood et al., 2013). These data suggest that harbour porpoise move either to the Minas Basin, or to deeper, cooler waters of the Minas Channel and outer Bay of Fundy, for the summer months (Wood et al., 2013).

Study Objectives

1. Determine harbour porpoise presence, including seasonal, diel, tidal, and lunar trends, at nearshore/weir sites in Minas Passage and Minas Basin, using passive acoustic monitoring devices; and
2. Assess relationships between harbour porpoise click detections, recorded by C-PODs and the icListenHF hydrophone, and the abundance of commercial and non-commercial fishes captured in two intertidal weirs.

Methods

Passive Acoustic Monitoring of Cetaceans

Harbour porpoise presence near each weir was monitored for the duration of the study using PAM technologies, specifically the C-POD (Chelonia, Ltd.) and icListenHF (Ocean Sonics Ltd.) hydrophones that can record cetacean echolocation click-trains. In late spring 2013, two co-deployed C-POD units were positioned seaward of each weir, near the low water mark, and were secured with rebar approximately 10 m apart from each other (Figure 38). Units were located approximately 150 m from the trap net at Bramber and approximately 50 m from the weir mouth at Five Islands. Two C-POD units were also deployed in the near shore environment close to the FORCE test site. C-PODs were configured to record frequencies between 20 – 150 kHz and to detect click-trains of any harbour porpoise within the instrument's listening range (~100-200 m). In addition to the two C-PODs, an icListenHF hydrophone was deployed at the Bramber site (late June-August). The icListenHF had a greater detection range (~500 – 1000 m) than the C-PODs and recorded all sounds ≤ 204.8 kHz. For unknown reasons, one of the two C-PODs deployed near the FORCE site malfunctioned and did not collect any data. At Bramber, C-PODs were operational except for periods in July when the icListenHF hydrophone was deployed. Deployment details are shown in Table 8.

Hydrophone Data Processing

Raw C-POD data was processed with Chelonia Ltd. Software Version 2.043, which filtered the data in order to distinguish between click-trains and other broadband sounds recorded by C-PODs. LUCY software (Ocean Sonics Ltd.) facilitated the icListenHF data processing. An autocorrelation function within LUCY was used to determine click trains within the icListenHF dataset. To reduce the error associated with low water levels, which can lead to false detections, only Detection Positive Minutes (DPMs, minutes during which at least one click train was detected) that were logged within three hours of high tide were considered in the study. The dataset on DPMs was examined for temporal and tidal range trends in porpoise presence, and for relationships with abundance of likely prey species in the weir catches.

<u>**Results**</u>

Harbour Porpoise Activity in the Nearshore Environment

A summary of deployment periods by site and hydrophone type, and average number of DPMs recorded per tide (high tide ± 3 hours) are shown in Table 8.

As expected, co-deployed C-POD devices recorded similar porpoise detections; however, the icListenHF hydrophone recorded a much higher number of DPMs per tide. This was anticipated as the icListenHF hydrophone has a greater detection range and listening volume (estimated at 11x that of C-PODs). The number of DPMs recorded at the Bramber weir site was significantly greater than the number of recordings at the Five Islands weir site. An absence of DPMs in the hydrophone data collected near FORCE suggests that porpoise were not within the expected detection range of the C-POD (100-200 m) during the deployment period (July – October).

There were very few DPMs (N=8) recorded by the two C-PODs near the Five Islands weir indicating near shore presence at Five Islands was very low. Consequently, no clear trends between the number of detected porpoise click-trains, the tidal height, and the abundance of porpoise prey species in weir catches at this site could be detected (Figure 39).

Of the three sites, Bramber showed the highest number of porpoise click-train detections; detections peaked in both spring and fall and were lowest in summer. The plots in Figure 40 show the DPMs per tide (high tide ± 3 hours) and the temperature at high tide.

Water temperatures during early July to late September exceeded 15°C, which is above the preferred temperature range of harbour porpoise (Yasui & Gaskin, 1986).

DPMs per tide, as recorded by the icListenHF and the two C-PODs during co-deployment of the two hydrophone types at the Bramber site in July and August, are shown in Figure 41. Breaks in the lines represent periods in July during which data was not recorded by C-PODs. Despite the differences in detection range and listening volume, DPM peaks recorded by the icListenHF are apparent in the C-POD dataset.

The frequency of C-POD DPMs relative to varying water height (binned in 2 m intervals) in the Bramber weir, weighted by the frequency of occurrence of water height at the weir, is shown in Figure 42. The duration covers 46 days of DPM records and continuous water height data. The relative frequency of C-POD DPMs increased with increasing water height up to the 6-8 m bin, after which there was no apparent change. In contrast the icListenHF plot (Figure 43) shows higher detections when water levels were low (2-4 m at the weir) than at any other time, and no clear differences among other water level heights.

Bramber weir C-POD data was examined for diel patterns in the porpoise DPMs (Figure 44). C-PODs were programmed to use Coordinated Universal Time (UTC). Diel patterns are evident in the data collected by both C-PODs; the total number of DPMs recorded at night (21:00 – 05:59 ADT) was more than double the total number of DPMs recorded during the daytime (09:00 – 20:59 ADT). The icListenHF detections, which represent activity only during the summer months, show slightly more detections logged during the daytime (Figure 45), but the ratio of DPSs: DPMs was higher during the early morning hours (01:00 – 04:59 ADT), suggesting greater foraging activity during the pre-dawn period.

Figures 46 and 47 include data for the C-PODs and icListenHF deployment at the Bramber site and display water height at high tide (m), the abundance of captured porpoise prey during seasonal sampling events and the intensive sampling period, and the DPMs per tide (high tide ± 3 hours). There was no apparent relationship in porpoise DPMs with tide height. The abundance of prey in the weir catches during the intensive sampling period shows significant variability in day-to-day and day/night abundance, with nighttime catches being greater. The largest catch of the season occurred during the night of July 15th

and overlapped with the intensive day/night weir sampling week. IcListenHF data displayed a seasonal peak in porpoise DPMs per tide during the same week; however, the peaks in fish abundance and porpoise DPMs per tide did not coincide.

Discussion & Conclusion

Harbour porpoise were rarely detected (high tide ± 3 hr) within the detection range of hydrophones deployed in the lower intertidal zone on Minas Basin's north shore. Porpoise were more commonly detected in the Southern Bight near the Bramber weir site from April to October, with peaks in presence occurring during April and May, and again during September and October. Low numbers of detections recorded during the summer months aligns with results from PAM studies within the Minas Passage. This suggests that during the summer, much of the harbour porpoise population moves into cooler, deeper waters in Minas Channel or other areas of the Bay of Fundy; perhaps porpoises are aggregating elsewhere for breeding, or are avoiding predators, such as great white sharks which have been detected (via telemetry) during July and August in Minas Passage.

Aside from nighttime highs in porpoise activity and highs in the abundance of porpoise prey species in the nighttime weir catches, no distinguishable trends were apparent between porpoise activity and the abundance of their prey. It is likely that short detection ranges of the hydrophones, especially C-PODs, limited any monitoring of porpoise movements in relation to their prey. For porpoise detection over a greater area, it is recommended that future studies consider the deployment of hydrophones in a transect arrangement, spanning from the low intertidal zone out to the middle of the Minas Basin.

Table 8: Hydrophone deployment details, total detection positive minutes (DPMs) per high tide (±3hr) and average number of DPMs recorded per high tide (±3 hr).

Site	Deploy-ment	Device	Data Start Date	Data End Date	Days With Data	Tides with Data	Total DPMs	Ave DPM/ Tide
Bramber	1	C-POD 1616	01 Apr	24 May	54	102	114	1.12
	1	C-POD 1880	01 Apr	24 May	54	102	131	1.28
	2	C-POD 1616	24 May	09 July	47	89	19	0.21
	2	C-POD 1880	24 May	29 June	37	70	14	0.20
	3	C-POD 1616	29 July	04 Oct	67	130	95	0.73
	3	C-POD 1880	29 July	04 Oct	67	130	116	0.89
	All	**C-POD 1616**	**01 Apr**	**04 Oct**	**165**	**321**	**228**	**0.71**
	All	**C-POD 1880**	**01 Apr**	**04 Oct**	**187**	**302**	**261**	**0.86**
	1	icListenHF	27 June	26 July	30	60	930	15.50
	2	icListenHF	29 July	29 Aug	32	61	1164	19.08
	All	**icListenHF**	**27 June**	**29 Aug**	**62**	**121**	**2094**	**17.31**
Five Islands	1	C-POD 643	17 April	21 June	66	127	4	0.03
	1	C-POD 1520	17 April	21 June	66	127	2	0.02
	2	C-POD 643	24 June	10 Oct	109	211	1	0.00
	2	C-POD 1520	24 June	08 Oct	107	208	1	0.00
	All	**C-POD 643**	**17 April**	**10 Oct**	**175**	**338**	**5**	**0.01**
	All	**C-POD 1520**	**17 April**	**08 Oct**	**173**	**335**	**3**	**0.01**
FORCE	1	C-POD 638	09 July	10 Oct	94	183	0	0
	1	C-POD 639	09 July	10 Oct	0	0	N/A	N/A

Figure 37: Image of a C-POD (top) and an icListenHF hydrophone (bottom) (Porskamp, 2013).

Figure 38: Image of a C-POD (left) and an icListenHF hydrophone (right) and battery pack located at Bramber weir site.

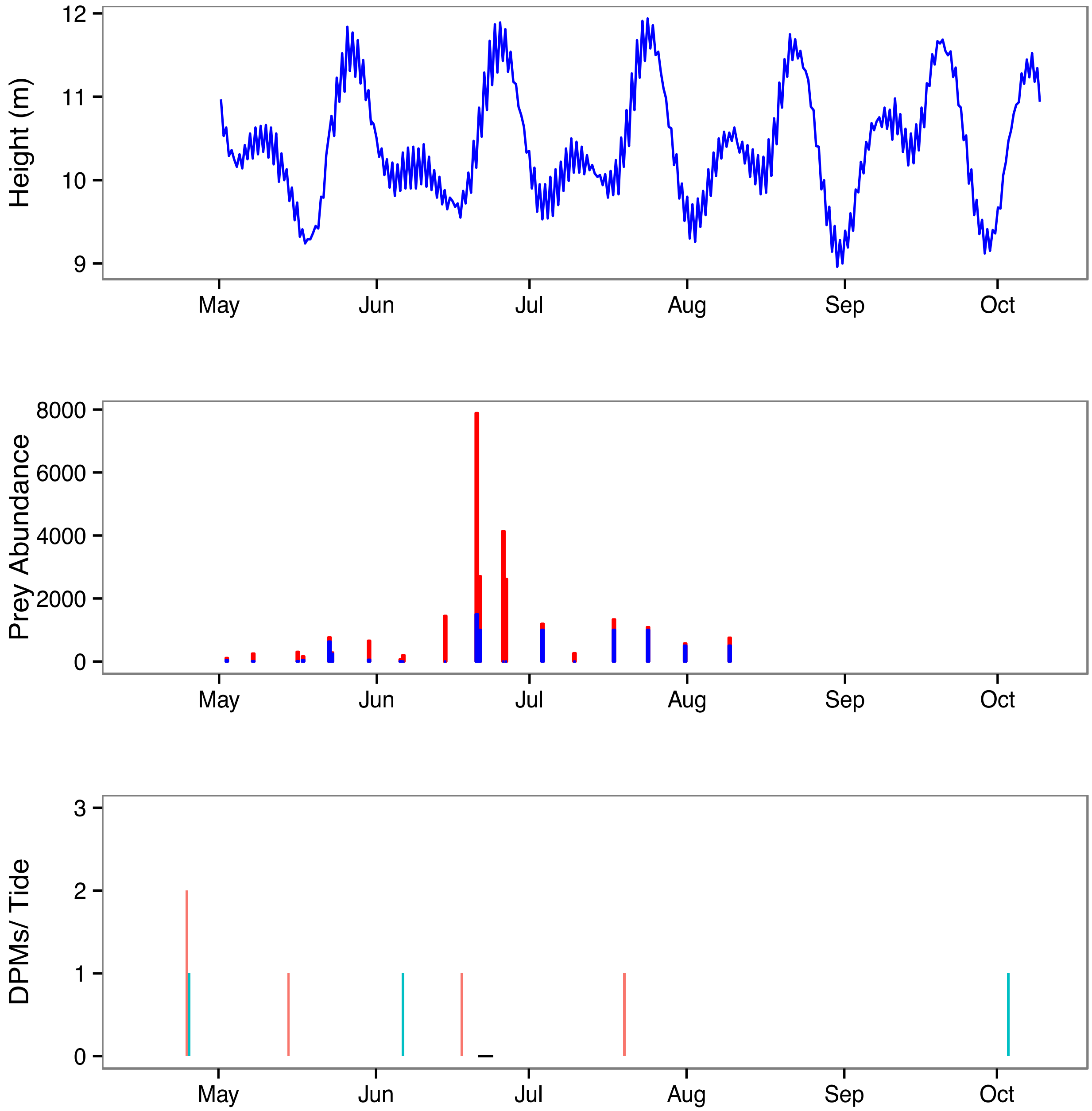
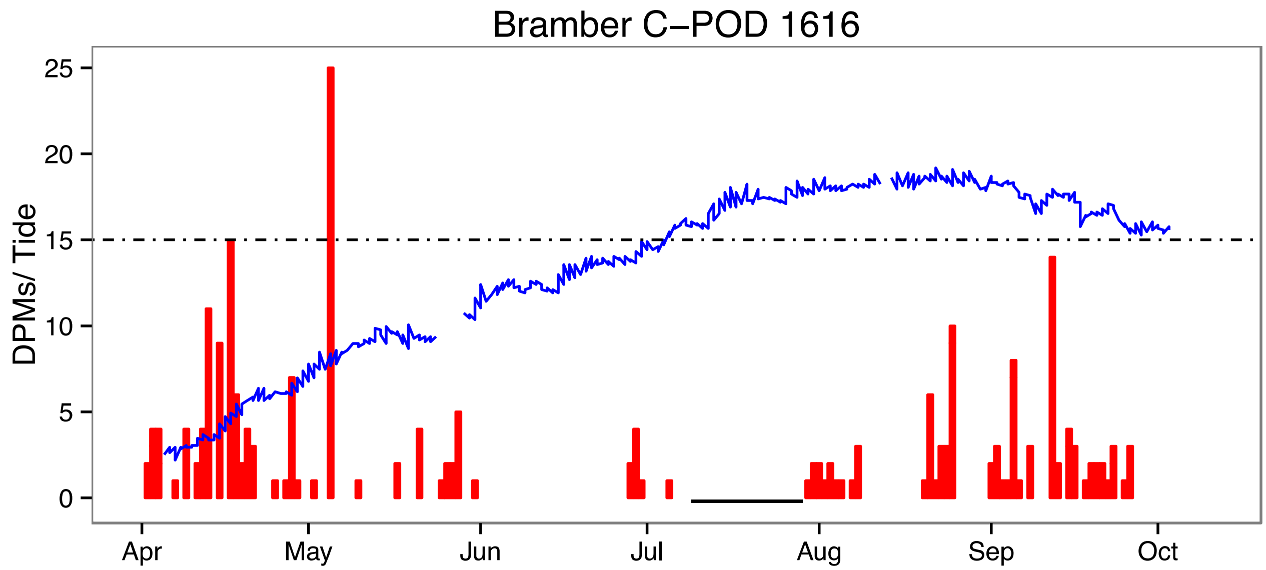


Figure 39: Water height at high tide (top) as recorded by HOBO data logger, abundance of porpoise prey as determined by weir catches (middle) and detection positive minutes (DPMs) per tide (high tide ±3 hr) for C-POD 643 (pink) and C-POD 1520 (teal) (bottom) at Five Islands, NS (17/04/2013 - 10/10/2013). The blue portion of the bars in the middle panel represents Atlantic Herring abundance (catch per tide), while the red depicts the abundance of all other common prey including American Shad, Alewife, Blueback Herring, Atlantic Mackerel, Atlantic Tomcod, Rainbow Smelt, Pollock, Red Hake, Silver Hake and Shortfin Squid. The black horizontal line (bottom) indicates a break in the C-POD data records during a period of battery turnover and data downloading (June 21-24 2013).



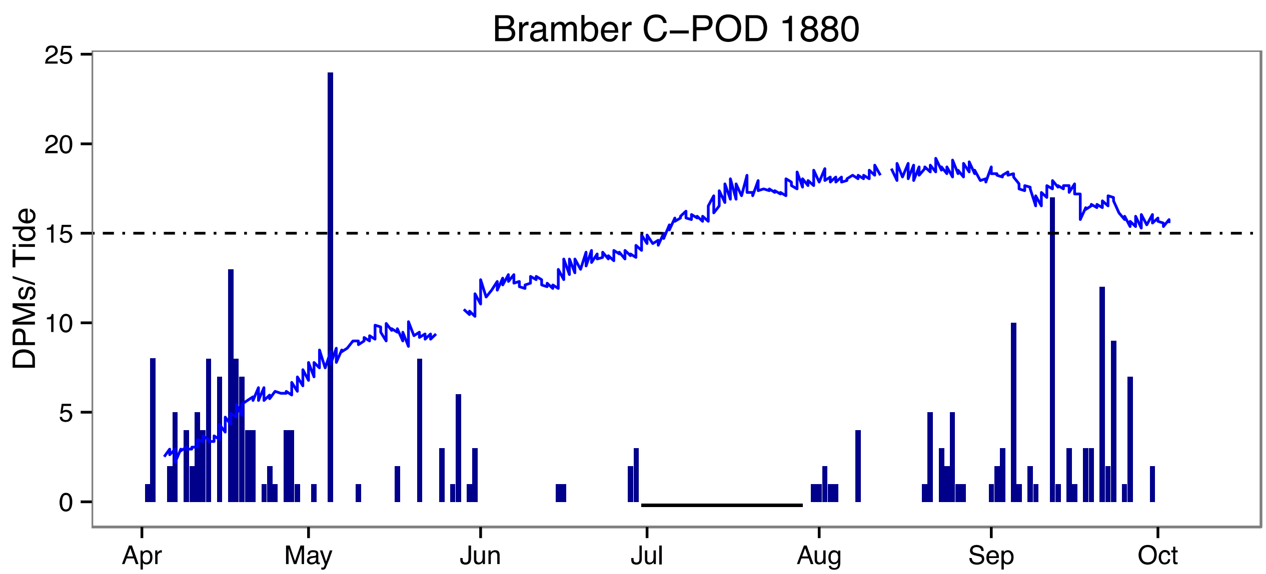


Figure 40: Detection positive minutes (DPMs) per tide (high tide ±3 hr) for C-POD 1616 (red) and C-POD 1880 (blue) during deployment at Bramber weir site, NS (01/06/2013 - 04/10/2013). The black horizontal line indicates a period in which the C-POD was not recording data (09/07/2013 - 29/07/2013 and 29/06/2013 - 29/07/2013). The dashed horizontal line indicates the upper limit of temperature preferred by porpoise. The blue lines represent the temperature at high tide as recorded by the HOBO data logger (same axis values as DPMs/Tide).

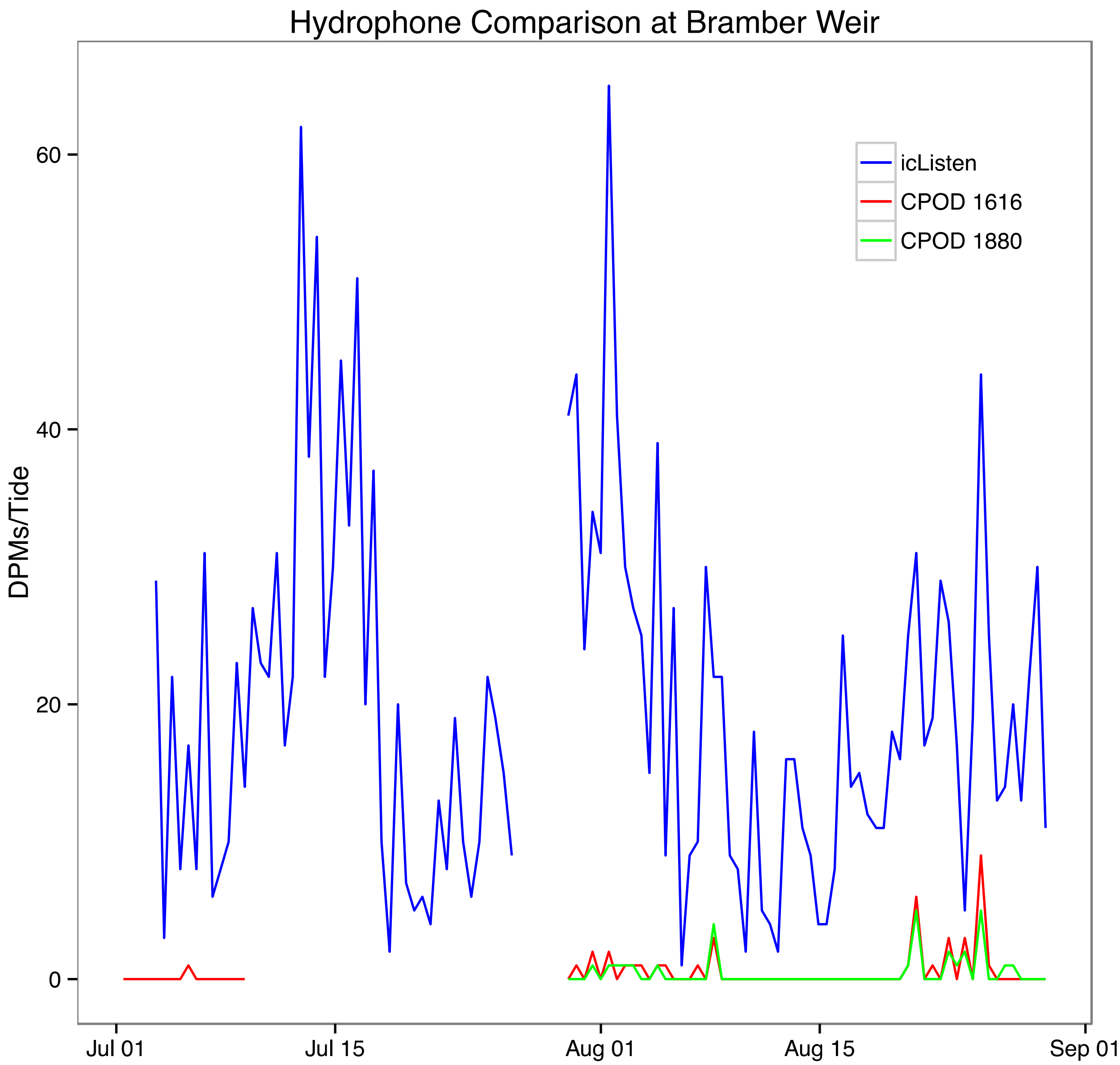


Figure 41: Detection positive minutes (DPM) per tide (high tide ±3 hr) for icListenHF, C-POD 1616 and C-POD 1880 during the co-deployment period at Bramber weir site, NS (27/06/2013 - 27/07/2013, 29/07/2013 - 29/08/2013). The break in icListenHF data records reflects a period of battery turnover and data download during 27-29 July.

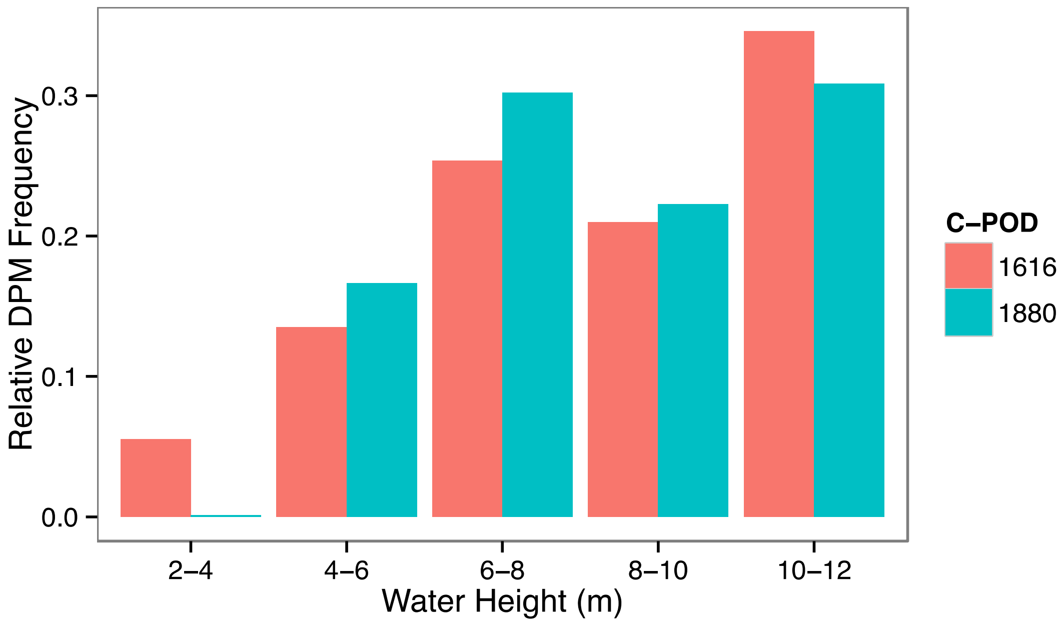


Figure 42: Relative frequency of detection positive minutes (DPMs, recorded by C-PODs 1616 and 1880) with increasing high tide water height (based on HOBO data). The data is weighted by the relative frequency of the water height ranges over a 46 day period in spring at Bramber, NS (06/06/2013 - 21/05/2013).

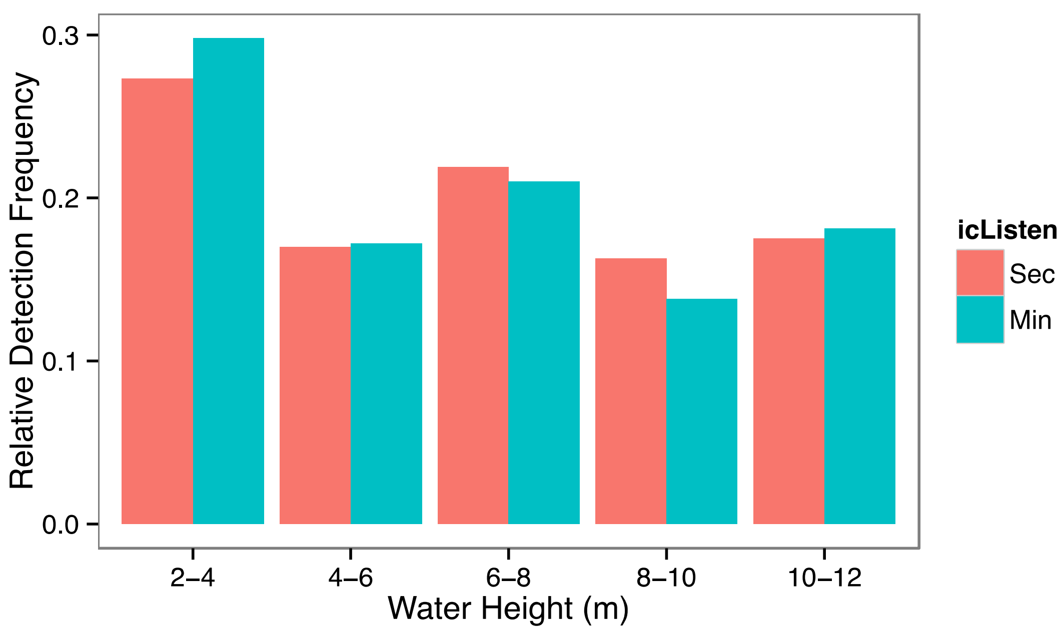


Figure 43: Relative frequency of icListenHF detection positive seconds (DPSs) and detection positive minutes (DPMs) at a particular water height (based on HOBO data), weighted by the relative frequency of that water height during the analyzed time period (high tide±3 hrs) over a 62 day period at Bramber, NS (27/06/2013 - 27/07/2013, 29/07/2013 - 29/08/2013).

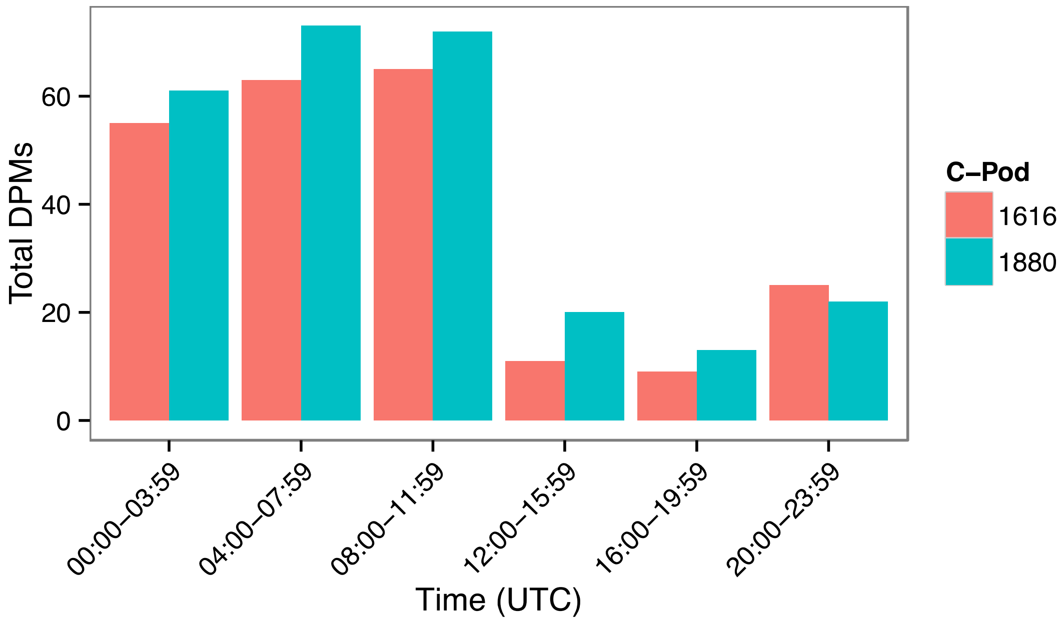


Figure 44: Total detection positive minutes (DPMs) recorded by C-PODs within 4 hour intervals at Bramber, NS (01/04/2013 - 04/10/2013).

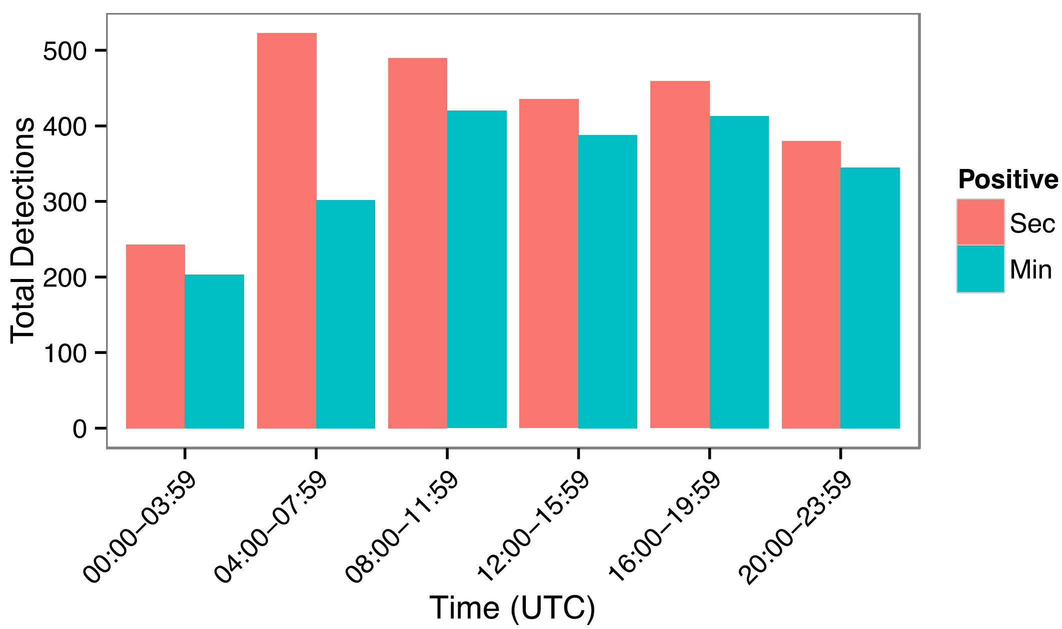


Figure 45: Total detection positive seconds (DPSs) and total detection positive minutes (DPMs) recorded by the icListenHF within 4 hour intervals over a 62 day period at Bramber, NS (27/06/2013 - 27/07/2013, 29/07/2013 - 29/08/2013).

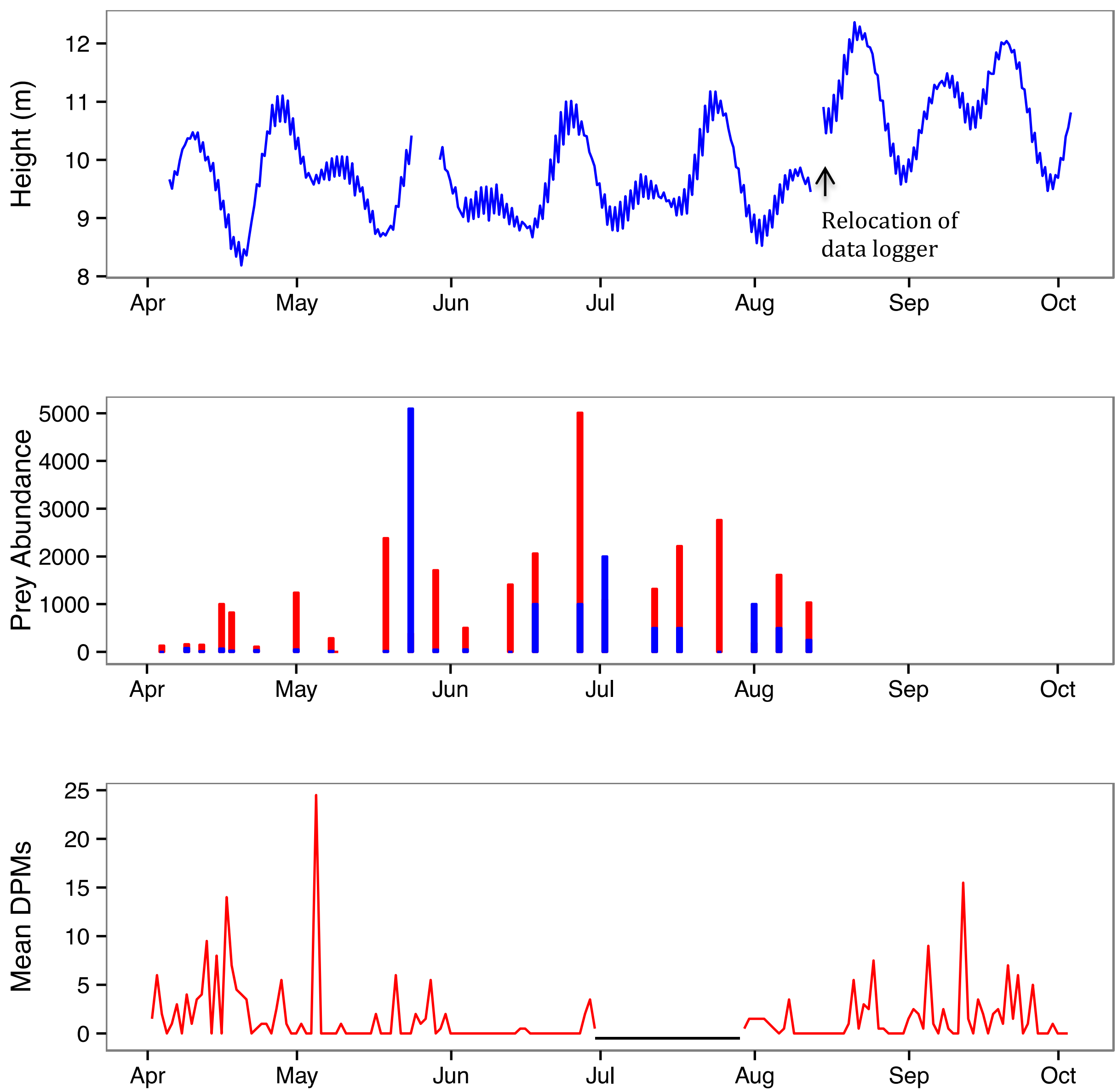


Figure 46: Water height at high tide (top) as recorded by the HOBO data logger, abundance of porpoise prey as determined by weir catches (middle) and detection positive minutes (DPMs) per tide (high tide ±3 hr) for C-PODs 1616 and 1880 (bottom) at Bramber (01/06/2013 - 04/10/2013). The blue portion of the bars (middle) represents Atlantic Herring abundance (per tide), while the red depicts the abundance of other common prey including American Shad, Alewife, Blueback Herring, Atlantic Mackerel, Atlantic Tomcod, Rainbow Smelt, Atlantic Pollock, Red hake, Silver Hake and Shortfin Squid. The black horizontal line (bottom) indicates a period in which the C-PODs were not recording data (29/06/2013 - 29/07/2013).

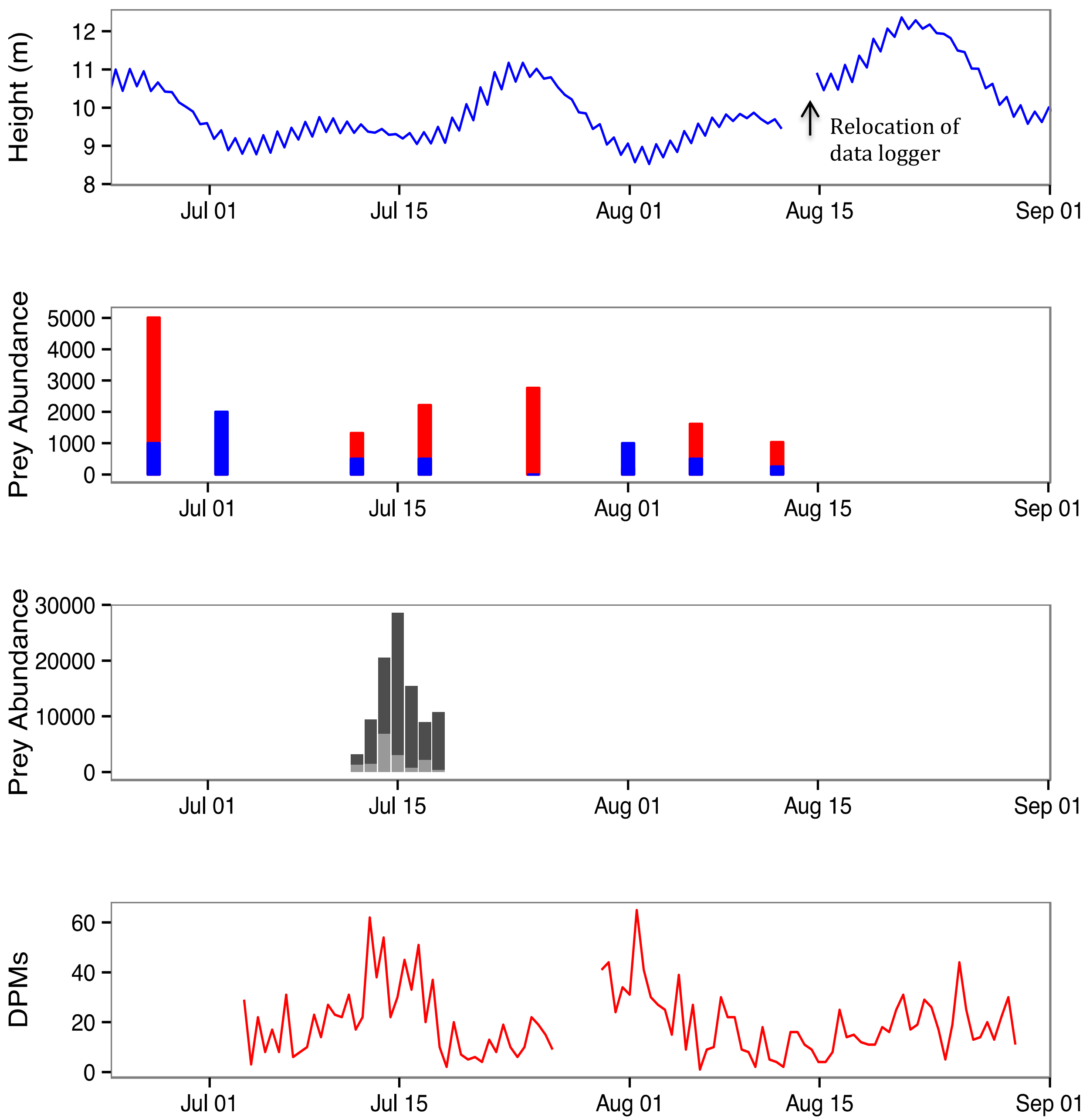


Figure 47: Water height at high tide (top) as recorded by the HOBO data logger, abundance of porpoise prey as determined by weir catches (upper-middle), abundance of prey species in weir catches during an intensive sampling period (lower-middle) and icListenHF detection positive minutes (DPMs) per tide (high tide ±3 hr) at Bramber, NS (27/06/2013 - 29/08/2013). The blue portion of the bars (upper-middle) represents Atlantic Herring abundance, while the red depicts the combined abundance of other common prey including American Shad, Alewife, Blueback Herring, Atlantic Mackerel, Atlantic Tomcod, Rainbow Smelt, Atlantic Pollock, Red hake, Silver Hake and Shortfin Squid. The light grey portions of the bars (lower-middle) indicate daytime fish catches of prey, while the dark grey portions indicate nighttime catches.

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APPENDIX I

Fish Sampling Methodology

Fish Sample Collection

Five Islands

The weir fisher used a traditional seine net to collect fish captured in the main pool as the tide ebbed. The seine was approximately 4 m x 1 m and was composed of ½" stretched netting. It did not include a cod end or floats on the headline. The fisher normally completed three separate seine hauls of the main collection pool. After each haul, by-catch was collected and placed in holding tanks for sampling, while targeted commercial species were gathered by the fisher and sorted based on species and/or size. Similar methodology was applied to the smaller collection pools near the mouth of the weir. Standard Ship-to-Shore 100L fish totes were filled with salt water to hold by-catch species prior to their release.

Sampling of the by-catch was conducted while the fisher collected and sorted the commercial catch. Identification, morphometric data, and counts were recorded and individuals were released into the main holding pond following the final seine haul. This prevented the same fish from being sampled or counted twice. Following completion of the sampling of non-commercial species, subsamples (≤ 50 individuals) of commercial catch species were sampled for abundance and morphometric measurements.

Bramber

The functionality of the weir at the Bramber site was the same as the weir in Five Islands; however, retention and collection methods differed because of the central trap net and greater overall size. The weir was strategically positioned in the intertidal zone to allow drainage through the trap net. While the majority of the catch was concentrated within the trap net, pools that formed along the longest wing held a portion of the catch.

Prior to the collection of the catch, multiple ship-to-shore 100L totes were filled with salt water to allow by-catch species to be sampled before being released into a holding pond. The fishes that were caught in pools along the wing were collected by the fisher, with the majority being concentrated into and collected from the collection gate. Once tidal waters had drained from the majority of the weir, the fisher(s) commenced collection of the catch by controlling the flow of the remaining restricted water. Dip-nets were used to catch fish when the trap net gate was opened. When the dip-nets filled with fishes, the gate was closed and the catch was emptied into a large fish box. Any non-target species were collected and placed in holding tanks for sampling. Commercial species were sorted into different categories and placed in totes.

Sampling the by-catch included species identification and counts (or estimates of abundance), and morphometric data collection. When by-catch species were not captured in large abundances, all individuals of each species were sampled before being released into the holding pond. If abundance was moderate to high, random subsamples of 25-50 individuals were selected for measurement. After the by-catch species were released into the holding pond, sampling of the commercial catch commenced.

APPENDIX II

Length - Weight Relationships of Common Fishes

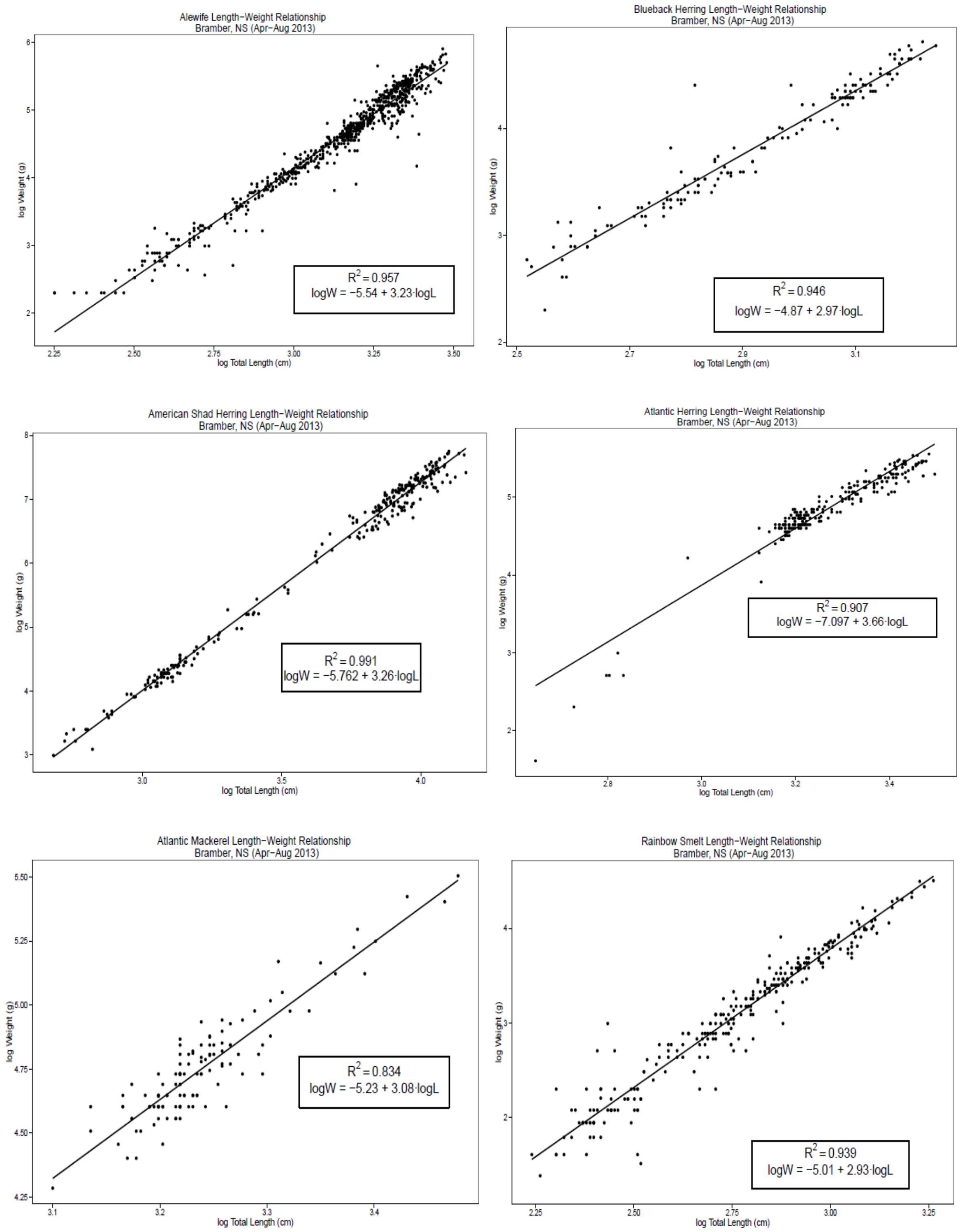


Figure A1: Linear regression of the natural logarithm transformations of total length (cm) and weight (g) of all specified fish sampled at the Bramber site.

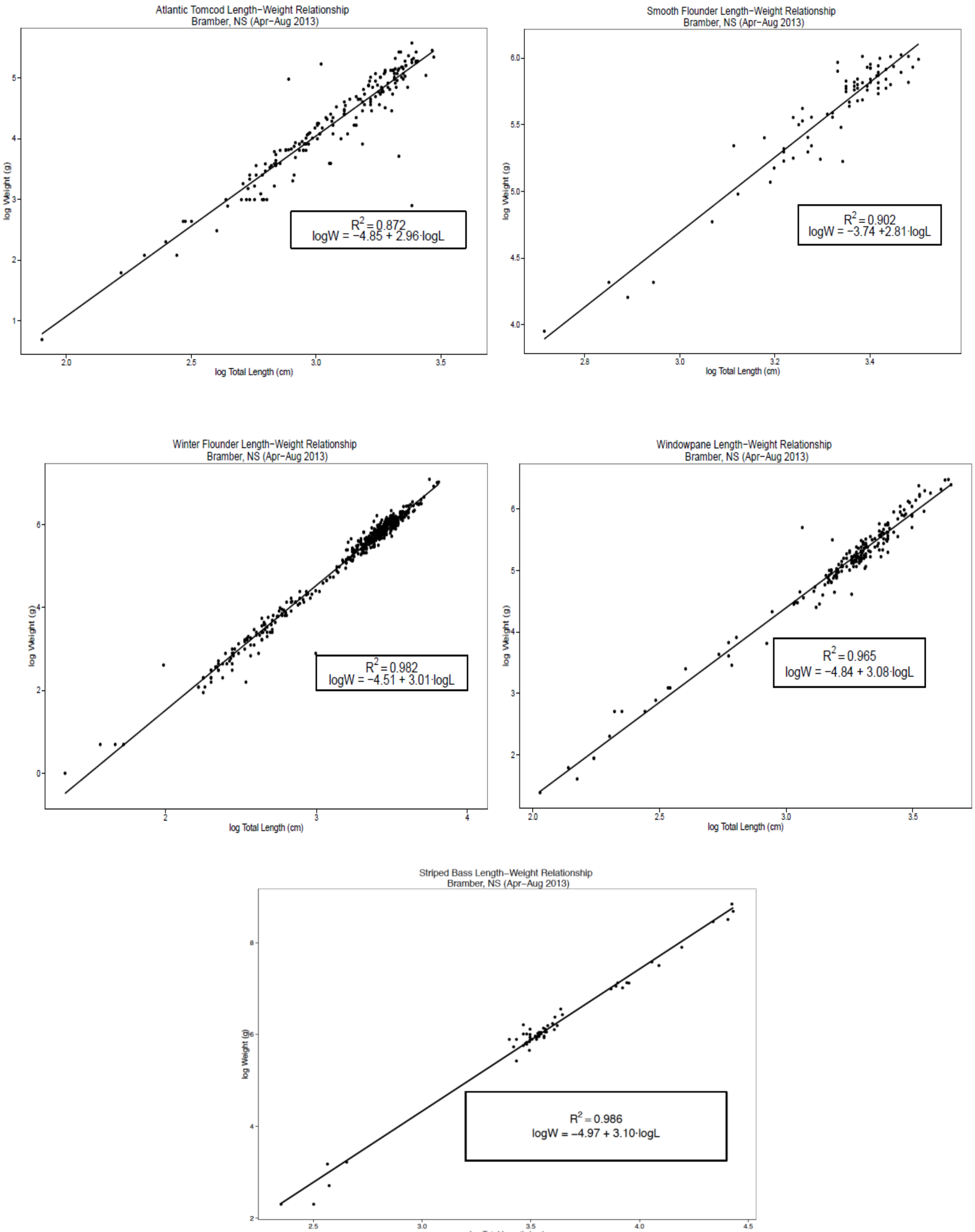


Figure A1 (Cont.): Linear regression of the natural logarithm transformations of total length (cm) and weight (g) of all specified fish sampled at the Bramber site.

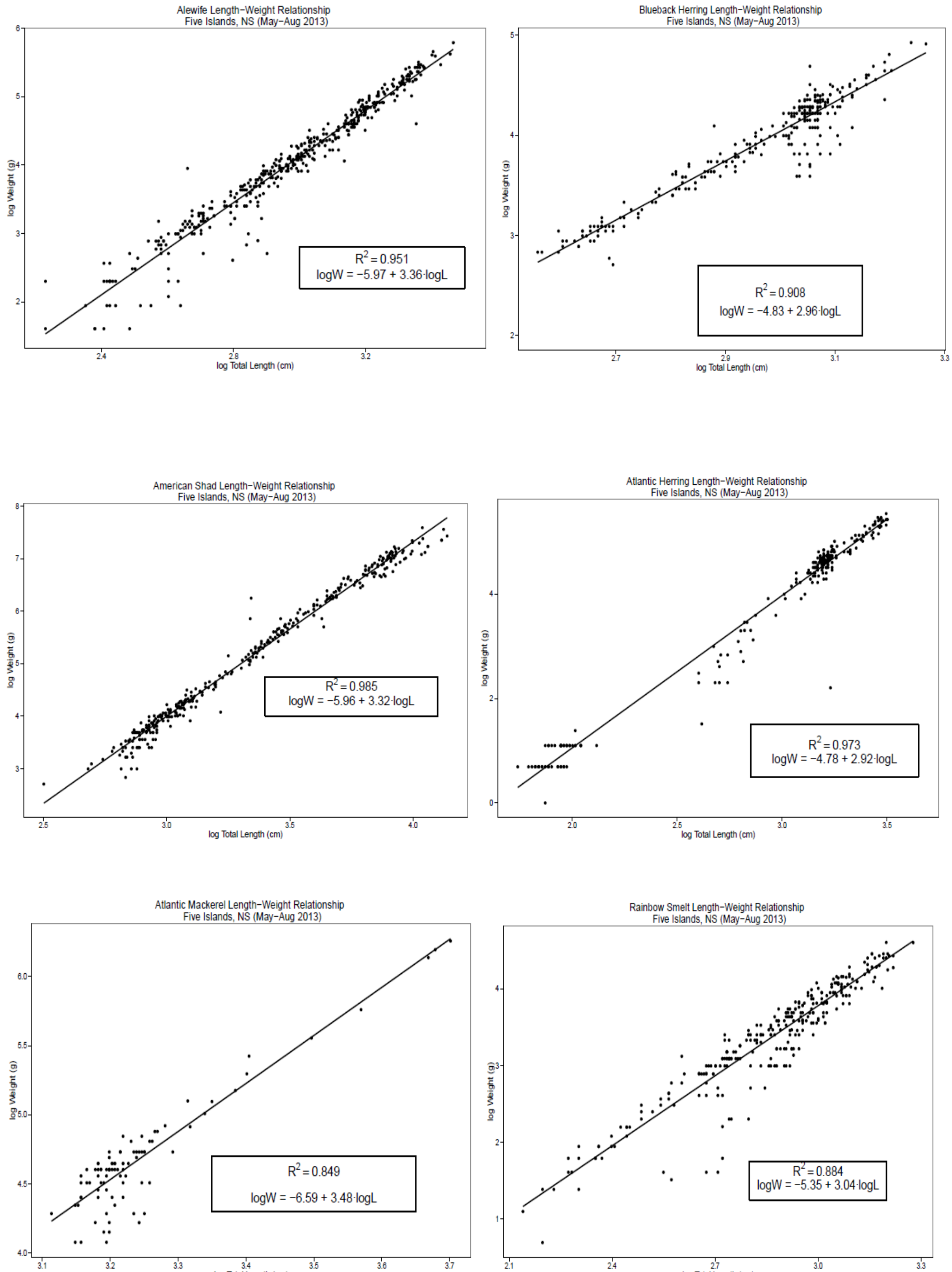
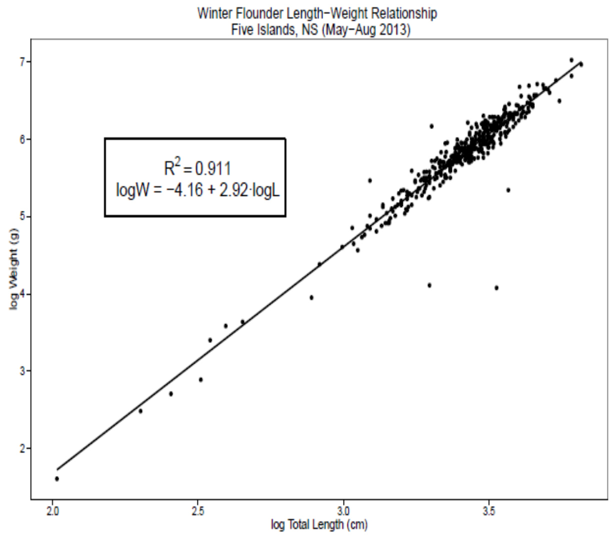


Figure A2: Linear regression of the natural logarithm transformations of total length (cm) and weight (g) of all specified fish sampled at the Five Islands site.



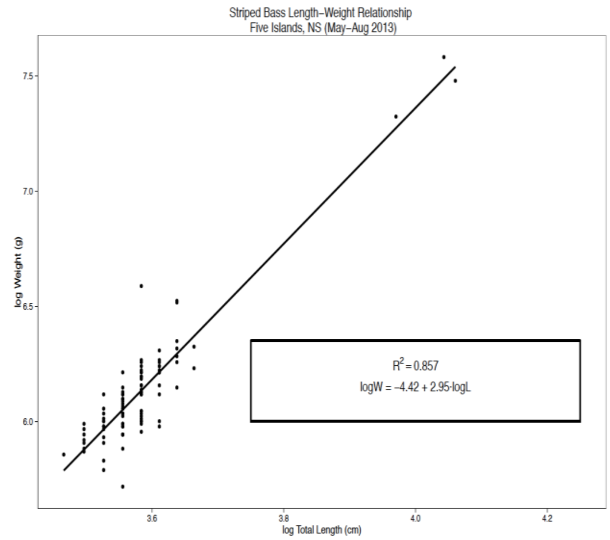


Figure A2 (Cont.): Linear regression of the natural logarithm transformations of total length (cm) and weight (g) of all specified fish sampled at the Five Islands site.