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DIET AND BIOLOGICAL CHARACTERISTICS OF ATLANTIC TOMCOD OR PUNAMU, *MICROGADUS TOMCOD* (WALBAUM, 1792) IN MINAS BASIN, NOVA SCOTIA

LINDSAY A. CARROLL[1], MICHAEL J. DADSWELL[1*], MATTHEW G. WARNER[1], DARREN PORTER[2], ALANNA SYLIBOY[3], FREDERICK G. WHORISKEY[4], SARA J. IVERSON[4] AND MICHAEL J.W. STOKESBURY[1]

[1]*Coastal Ecology Laboratory, Department of Biology, Acadia University, 33 Westwood Avenue, Wolfville, NS B4P 2R6*

[2]*Marine Institute of Natural and Academic Science, Avonport, NS*

[3]*The Confederacy of Mainland Mi'kmaq, Department of Aquatic Resources and Fisheries Management, 52 Legends Avenue, Millbrook, NS B6L 0A3*

[4]*Ocean Tracking Network, Dalhousie University, 1355 Oxford Street, Halifax, NS B4H 4R2*

ABSTRACT

Atlantic tomcod are abundant in the Bay of Fundy, but their diet is unreported for Minas Basin. In this study prey content and biological characteristics of tomcod collected in the Avon River estuary of Minas Basin were examined. Their diet was numerically dominated by the amphipod *Corophium volutator* (Pallas, 1766) (Rate of Occurrence (RO) = 73.2%). Other major prey taxa consumed included *Crangon septemspinosa* Say, 1818 (29.3%), *Gammarus spp.* (19.5%), Polychaeta (14.6%), Portunidae (12.2%), Teleostei (9.8%), Isopoda (7.3%), and Mollusca (3.3%). Of stomachs examined only 8.9% contained unidentifiable prey items. Every tomcod examined except one contained prey and the fullness index (HI) varied between 0.01-5.85%. Both mean total length and total body weight of females was significantly greater than for males (254 mm vs 202 mm; 143 g vs 78 g), and the condition factor (K) of both sexes was similar throughout the sampling period (Mean ± SD; 0.79 ± 0.13). Both mean male and female gonadosomatic index (GSI) increased significantly when approaching the winter spawning period, rising from 1.2 in early October to 11.6 by mid-December. The diversity of prey consumed indicated that tomcod fed opportunistically, but their predominate consumption of *C. volutator* was likely

* Author to whom correspondence should be addressed: mike.dadswell@acadiau.ca

linked to the large populations of this amphipod on the intertidal mudflats of Minas Basin.

Keywords: Atlantic tomcod, Bay of Fundy, condition factor, *Corophium volutator*, fullness index, gonadosomatic index.

INTRODUCTION

Atlantic Tomcod *Microgadus tomcod* (Walbaum 1792) are distributed along the northeastern coastline of North America from southern Labrador, Canada, south to Chesapeake Bay, US (Cox 1921, Stewart & Auster 1987), and have two known landlocked, freshwater populations in Grand Lake, Newfoundland and Lac Ste. Jean, Quebec (Scott & Scott 1988). Marine tomcod populations occupy estuarine and shallow inshore habitats but also occur in deeper waters offshore (Peterson *et al.* 1980, Scott & Scott 1988). Within the Bay of Fundy (BoF) tomcod occupy most regions including Passamaquoddy Bay (Peterson *et al.* 1980, Fletcher *et al.* 1982), Cumberland Basin (Salinas 1980, Dadswell *et al.* 1984), Cobequid Bay (Bousfield & Leim 1959), and Minas Basin (Dadswell *et al.* 2020, Dadswell & Rulifson 2021).

The life cycle of marine populations of Atlantic tomcod appears to be similar throughout their range. Tomcod spawn in brackish estuaries and freshwater streams with eggs hatching approximately two months after spawning when the larvae immediately disperse seaward (Peterson *et al.* 1980). Larvae are planktonic and young-of-the-year remain in their natal estuary the summer following birth where retention in the estuary is facilitated by tidal currents (Stewart & Auster 1987). Growth rate of tomcod is greatest in their first year and they may begin reproduction during this period (Salinas & McLaren 1983). Tomcod are determinate spawners, and during reproduction, a single female deposits an average of 20,000 eggs (Range 6000-66,000) depending on her size (Vladykov 1955, Schaner & Sherman 1960). Tomcod can live up to 4 years and grow to a maximum reported length of 38 cm (Scott & Scott 1988). After their first year of life, they often move to bays and coastal waters beyond their natal estuary (Bigelow & Schroeder 1953, Stewart & Auster 1987).

Atlantic tomcod are also known as "frostfish," given their propensity to school in creeks, rivers, and estuaries with the approach of cold weather leading into their winter spawning season (Cox 1921, Scott & Crossman 1973, Fletcher *et al.* 1982). Their ovaries increase as much as nine times in weight from October to December (Schaner

& Sherman 1960). Tomcod spawning season begins in November and continues into February, with peak spawning activity occurring during December to January (Peterson *et al.* 1980, Williams *et al.* 2009). This period of reproductive activity is captured in the Mi'kmaw calendar and denoted Punamujuik'us, which translates to 'spawn of the tomcod' (Kavanaugh *et al.* 2004). In Mi'kma'ki, which encompasses much of Atlantic Canada, including all of Nova Scotia, Mi'kmaw communities have long observed the natural pattern of tomcod migrating upstream to spawn and tomcod have traditionally been accessible to Mi'kmaw harvesters during winter.

The Atlantic tomcod diet has been studied in river and estuary systems of Cobequid Bay and Cumberland Basin (Bousfield & Leim 1959, Salinas 1980, Dadswell *et al.* 1984), and in estuarine areas of New England (Cox 1921, Stewart & Auster 1987). Early planktonic larval stages of tomcod prey almost exclusively on planktonic copepods (Cox 1921), while older benthic life stages feed mainly on crustaceans including amphipods, isopods, mysids, and shrimp in addition to the larvae of shore crabs (Scott & Crossman 1973, Salinas 1980, Stewart & Auster 1987). In Cumberland Basin, the amphipod *Corophium volutator* (Pallas, 1766) was the major prey item (Salinas 1980, Dadswell *et al.* 1984). Upon reaching age one, tomcod have been observed to prey on small inshore fish species including sticklebacks (Gasterosteidae) and the young of other fish, such as striped bass *Morone saxatilis* (Walbaum, 1792), alewife *Alosa pseudoharengus* (Wilson, 1811), American shad *Alosa sapidissima* (Wilson, 1811), and Atlantic herring *Clupea harengus* Linnaeus, 1758 (Cox 1921, Scott & Crossman 1973). In the Miramichi River, New Brunswick, tomcod captured in nets had gorged on rainbow smelt *Osmerus mordax* (Mitchill, 1815) (Hanson & Courtenay 2020). Cannibalistic predation has also been reported (Cox 1921, Scott & Crossman 1973). Understanding the diet of fishes, including that of tomcod, and its influence on growth can be vital to understanding their ecological role and their productive capacity.

Atlantic tomcod are seldom fished commercially (Scott & Scott 1988, Dadswell *et al.* 2020) and it can be challenging to sample large numbers to describe their diet. They are widely distributed in the western Atlantic, but their movement is not well known, and their diet may vary between regions. Habitat variation among populations suggests they have a broad, varied diet but information collected on their feeding habits in one area may not necessarily apply to others, particularly when compared to other regions of the Bay of Fundy.

Tomcod are important prey for predatory species such as striped bass (Dew & Hecht 1976, Watson 1987) and bald eagle *Haliaeetus leucocephalus* (Linnaeus, 1756) (Reid 1982). Striped bass may selectively target tomcod in summer during times when alternate prey is scarce. Bald eagles target tomcod in early winter when they are aggregated near their spawning sites.

The range of Atlantic tomcod extends into tidal river systems throughout Minas Basin, including the Avon River and adjoining Cogmagun and Halfway Rivers (Fig 1; Dadswell *et al.* 2020), the sites selected to investigate the tomcod diet. Since these tidal rivers are influenced by the tidal forcing of the BoF, they present dynamic foraging challenges to fish during periods of high tidal flow. Like Cumberland Basin (Salinas 1980, Dadswell *et al.* 1984), tomcod is extremely abundant in the turbid nearshore regions of Minas Basin (Dadswell & Rulifson 2021).

To assess the importance of Minas Basin for tomcod, an understanding of their feeding ecology was needed. The objective of this study was to determine tomcod diet and biological characteristics in Minas Basin prior to their spawning period during winter.

METHODS

Study Site Description

Minas Basin (Fig 1) is a unique and dynamic macrotidal marine environment with an average semi-diurnal tidal fluctuation of 16m and a diverse aquatic community (Bousfield & Leim 1959). The large tidal amplitude results in strong tidal currents reaching 4 m/s (Parker *et al.* 2007). The large tides and strong currents cause thorough mixing of marine and inflowing fresh water which results in a complete lack of thermal gradients or haloclines in the Basin.

Summer water temperatures are between 15°C and 20°C and occasionally higher, and winter temperatures drop as low as -1.5°C (Parker *et al.* 2007). These extreme temperature differences are due to the large surface area of the intertidal mudflats that are regularly exposed by the tides. Salinity in the central portion of Minas Basin during summer averages 30 but during winter there is a reduction in freshwater runoff from major rivers which results in less dilution

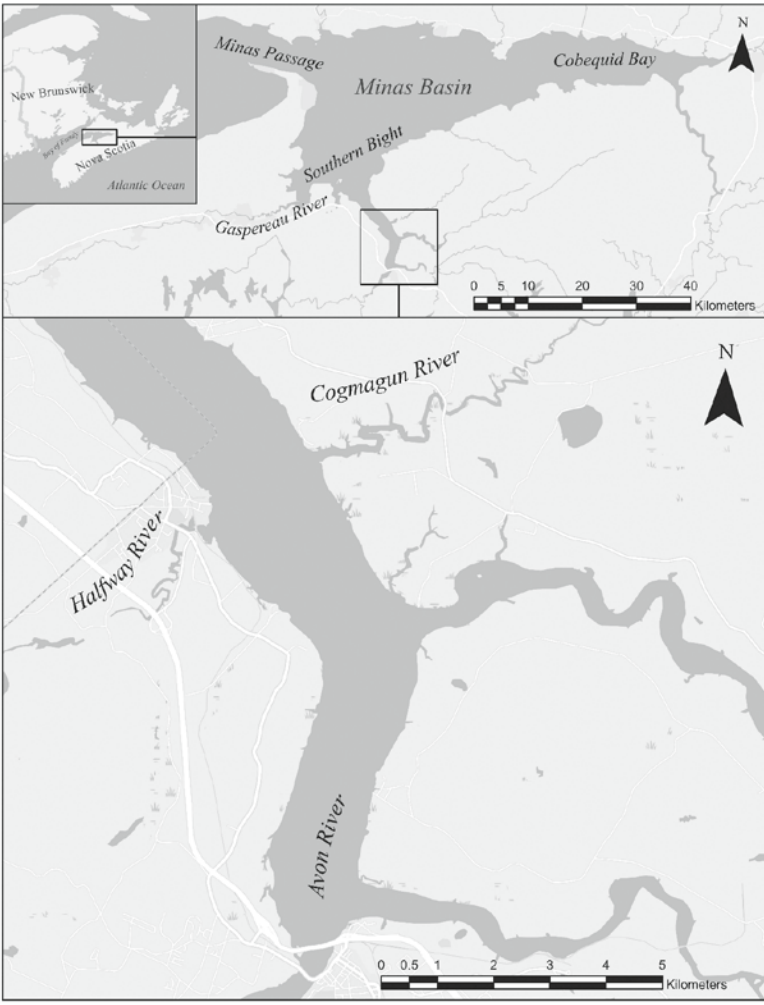

Fig 1 **Map of the Avon River, Nova Scotia (lower) highlighting the three sites (Halfway River, Cogmagun River and Avon River) where Atlantic tomcod were captured for sampling. Inset map (upper) indicates location of sites relative to the Minas Basin and the Canadian Maritimes.**

of the Basin (Bousfield & Leim 1959). Minas Basin is a productive estuarine environment supporting high densities of invertebrates across expansive intertidal mudflats, providing an ideal foraging area for a multitude of resident and migratory species (Hamilton *et al.* 2006, McLean *et al.* 2013, Kendall *et al.* 2018).

Minas Basin is a unique oceanographic extension of the Bay of Fundy as the biota differ substantially. The BoF supports a coldwater fauna, whereas Minas Basin is substantially warmer in the summer and colder in the winter due to its sheltered situation, resulting in a mixture of species categorized as southern, temperate, boreal, Arctic, and European (Bromley & Bleakney 1984). One of the most abundant macro-invertebrates residing in the BoF, the amphipod *C. volutator*, may be found on intertidal mudflats in densities upwards of 10,000 per m^2 (Barbeau *et al.* 2009). *Corophium volutator* serve as an especially important food source for fishes (McCurdy *et al.* 2005, McLean *et al.* 2013) and migratory shorebirds (Hamilton *et al.* 2006).

Sample Collections

To test experimental methods a total of 20 Atlantic tomcod were collected from the Halfway River and Cogmagun River in the Avon estuary of Minas Basin (Fig 1; 45° 04′N, 64° 09′W) during May 2019 using eel pots (Hubert 1996) baited with gaspereau (*Alosa spp.*) and left in the water for 60-90 minutes during the rising tide. Fish were randomly selected for sampling and euthanized using a lethal dose of dissolved anesthetic (Aqualife, tricaine methanesulfonate [TMS or MS-222]) then placed on ice until frozen for preservation on the same day (within a few hours of euthanasia). For stomach contents analysis, fish were allowed to thaw, measured for total length (TL ± 1 mm) and total body weight (BW ± 1 g). Stomachs were extracted then labeled and refrozen until sampling. Sampling was completed under Acadia Animal Care Committee protocol # 07-18R#1A#1.

From September to December 2019, another 157 Atlantic tomcod were collected on an approximately weekly basis from the Halfway River, Cogmagun River and Avon River study sites using baited eel pots. Each tomcod was euthanized on site by means of blunt force trauma (cranial concussion), then placed on ice and returned to the lab for analysis (normally a few hours after euthanasia). Tomcod were measured for TL, BW, and sexed. Stomachs were removed from 110 tomcod and preserved in 70% ethanol to prevent decomposition (Bowen 1996). Sampling was completed under Acadia University Animal Care Committee protocol #10-19.

Diet Analysis

The 20 Atlantic tomcod collected in May 2019 were thawed and used for preliminary sampling. The wet weight of each stomach was determined to the nearest 1 g. Stomachs were opened and contents spread onto a petri dish using dissection instruments. Items were sorted and identified based on morphological features. Stomach content samples were examined under a dissecting microscope to confirm identification. Prey items were recorded for each stomach on a presence/absence basis and identified to the lowest possible taxonomic level. Enumerating individual prey, however, was not possible due to advanced digestion, rendering it difficult to consistently produce accurate counts (e.g., amphipods may have been identifiable but often whole individuals with all legs/mouth parts intact were not consistently present).

The wet weight of the 110 stomachs collected during fall 2019 were each determined to the nearest 1 g and the total stomach contents were removed and weighed to the nearest 1 g. Gonads were removed from 82 individuals and gonad wet weight (GW) determined to nearest 1 g.

Items observed in the 110 stomachs collected during the fall sampling period were recorded on a presence/absence basis (Bowen 1996). For identification of species and groupings to the lowest possible taxonomic level, a key specific to the fauna found in Minas Basin was used (Bromley & Bleakney 1984). Post-capture digestion may have resulted in loss of dietary information, so, when possible, items were identified based on hard parts remaining, such as bones and otoliths found in stomach samples using a guide (Rojo 2015). Items including fishing bait, plant detritus, soil detritus and unidentifiable contents were also recorded when encountered.

Data Analysis

The percent rate of occurrence (RO) of each prey taxa found in sampled Atlantic tomcod was determined as the total stomachs observed to contain each prey grouping in relation to the total stomachs examined (%). Some prey items were not identified to genus or species level and were combined into a higher taxonomic level based on similarity or close relation (e.g., unidentified crab species and green crab were grouped together in family Portunidae, Table 1). The percent observed RO of prey items was then separated for males and females where sexed individuals were recorded.

A cumulative prey curve was created based on each encounter of each newly identified prey item in chronological order and was used to assess if sample size was sufficient to accurately describe the diet

Table 1 Taxonomic identification summary of prey encountered in Atlantic tomcod stomachs collected during May-December 2019 in Minas Basin expressed as percent rate of occurrence (%) for male (n = 33), female (n = 57), and combined (n = 123) with undetermined sex (n = 33). Amphipoda* that could not be identified to a lower taxon.

Prey	Male (%)	Female (%)	Combined (%)
AMPHIPODA*	66.7	75.4	78.1
Corophium volutator	93.9	64.9	73.2
Gammarus spp.	15.2	15.8	19.5
DECAPODA: CRANGONIDAE			
Crangon septemspinosa	27.3	24.6	29.3
PORTUNIDAE	18.2	10.5	12.2
Carcinus maenus	12.1	3.5	7.3
ISOPODA	6.1	7.0	7.3
CEPHALOPODA	3.0	3.5	2.4
BIVALVIA	0.0	1.8	1.6
POLYCHAETA	12.1	15.8	14.6
TELEOSTEI			
Gaspereau (bait)	60.9		
Microgadus tomcod	3.0	7.0	5.7
Alosa aestivalis	3.0	1.8	3.3
Menidia menidia	0.0	1.8	0.8
MAMMALIA: RODENTIA	1.8	0.0	1.8
Unidentified Prey	3.0	10.5	8.9

[a] Also plant detritus - 39.8%, soil detritus - 4.9%, and empty- 0.1%

composition of tomcod. To determine if the cumulative prey curve reached an asymptote, we fitted a straight line to the last 4 points of the curve and compared the slope of this line with a line of slope 0 (Preti *et al.* 2012; Varela *et al.* 2020). The degree of gut fullness was calculated as Hureau's Index (HI) using the equation:

HI (%) = (ingested biomass [g] / total body weight [g]) x 100 (Berg 1979).

Biological characteristics among fish (TL, BW) with an identified sex were compared with one-way ANOVA tests followed by a post-hoc Tukey test if a significant *p*-value was produced. Fish were grouped to compare sexes within and between sampling sites, as well as overall. Biological characteristics of captured tomcod were also compared for condition factor and their gonadosomatic index. The Fulton condition factor (K) was determined where:

$K = (BW\ [g] / TL^3\ [mm]) \times 100{,}000$ (Anderson & Neuman 1996).

The gonadosomatic index (GSI) was determined where:

$GSI = (GW[g] / BW\ [g]) \times 100$ (Flores *et al.* 2019).

The condition factor was plotted in relation to date to examine trends during the sampling period and changes over time were tested using one-way ANOVA and a post hoc Turkey's test. The variation in GSI was examined using date as a factor to determine if there were any significant difference between sampling days, and therefore during the sampling period and tested with a one-way ANOVA. If the ANOVA returned a *p*-value of less than 0.05, it was deemed significant, and a post-hoc Turkey's test was performed. Correlation analysis was performed using HI vs GSI to determine if there was a relationship between these variables.

RESULTS

Diet

Of the 177 Atlantic tomcod collected, 123 were suitable for examining dietary items and 110 had stomachs and stomach contents weighed. The cumulative prey curve constructed from the dietary analysis was substantially reduced after 100 stomachs were assessed (Fig 2) and reached an asymptote ($y = 0.3x + 17.5$) that was not significantly different from 0 (*T* – test; $P = 0.2254$) resulting in a reasonable confidence that a large portion of the overall diet was identified. Only one stomach was empty with no organic or inorganic material present. Mean and standard deviation of gut fullness (HI) across samples was $1.14 \pm 1.06\%$ ($n = 109$) and ranged from 0.01- 5.85%.

Among Atlantic tomcod stomachs examined 92.7% contained prey items. Taxa most frequently ingested by tomcod included *Corophium volutator* (73.2%), sand shrimp *Crangon septemspinosa* Say, 1818 (29.3%) and *Gammarus spp.* (19.5%; Table 1). Amphipods were the major prey class consumed based on occurrence (78.1%), and when comparing males to females, amphipods (including both *C. volutator* and *Gammarus* spp.) were the primary prey class consumed by females (75.4%), while *C. volutator* alone were the primary prey class

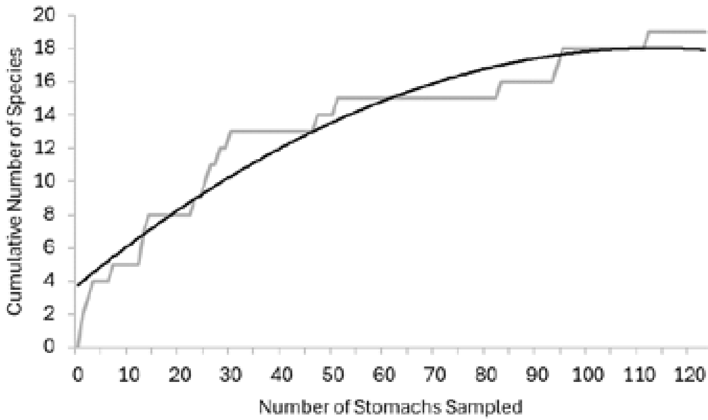

Fig 2 Cumulative prey curve for Atlantic tomcod diets indicating number of new taxa encountered relative to number of stomachs containing prey (n = 123). The gray line is the increase of prey item values as they were encountered, while the black is a polynomial line calculated from the data with an equation of y = -0.001x2 + 0.243x + 4.032.

consumed by males (93.9%; Table 1). A few other amphipods were noted but they could not be identified to a lower taxon.

Polychaete worms were present in 14.2% of stomachs examined but they were unable to be identified to a lower taxonomic level due to advanced digestion (Table 1). Crabs (Portunidae) were observed in 12.2% of stomachs examined of which 7.3% were juvenile green crab *Carcinus maenas* (Linnaeus, 1758). The occurrence of isopods in stomachs was low (7.3%) and included *Idotea baltica* (Pallas, 1772), *Idotea phosphorea* (Harger, 1873), *Chiridotea coeca* (Say, 1818), and *Politolana polita* (Stimpson, 1853). Identified fishes included Atlantic tomcod, blueback herring *Alosa aestivalis* (Mitchill, 1815) and Atlantic silverside *Menidia menidia* (Linaeus, 1766). Squid remains were observed, which were probably longfin squid *Doryteuthis pealei* (Lesueur, 1821). There were two observations of bivalve remains, both of which were probably juvenile amethyst gem clam *Gemma gemma* (Totten, 1834). Trace amounts of digested tissues were present in 11 of the stomachs, however, they could not be identified, and they were assessed as gaspereau bait remains. One sample contained the intact rear half of a small rodent, which may have been either a species of mouse or vole based on the colour and type of fur.

Gaspereau used as bait occurred in 60.9% of tomcod stomachs examined (Table 1). Plant detritus was present in 39.8% and soil detritus in 4.9% of stomachs but amounts were minimal and were mostly accompanied by other items. Only one stomach was completely empty with no organic or inorganic material present. Parasitic Nematoda were observed in 7.3% of stomachs examined but they were not considered to be part of the diet.

Biological Characteristics

Among sampled Atlantic tomcod females were significantly longer (mean TL, 254 mm vs 202 mm) and heavier (mean BW, 143 g vs 78 g) than males (Turkey's test, TL and BW, $P < 0.0001$). The range of TL and BW for all fish from the fall sampling period was, 140-340 mm and 24-342 g, respectively (Table 2). Male and female fish compared for TL and BW between the Avon and Cogmagun River sampling sites were not significantly different (one-way ANOVA). Females had higher mean gonad weight and stomach weight than males (Table 2), but these values were also not significantly different (one-way ANOVA).

The condition factor (K) remained relatively constant throughout the sampling period with a mean ± SD of 0.79 ± 0.13 (Fig 3). Condition factor appeared to decline in relation to fall-winter sampling date but did not demonstrate a particularly strong trend. Although the change in K over time was significant (one-way ANOVA, $F_{13, 53} = 6.39$, $P = 4.67 \times 10^{-7}$), the outcome of a post-hoc Turkey's test indicated that there were no significant differences between results from samples at the beginning and end of the September to December collection period.

Mean GSI of male and female tomcod increased during the fall sampling period by approximately 10 times from 1.2 on 1 October 2019 to 11.6 on 19 December 2019 with one female having a GSI of 24.9 (Fig. 3). Comparing GSI over time for 48 females and 30 males revealed that there was a significant difference between dates of all samples taken (one-way ANOVA, $F_{14, 66} = 6.387$, $P = 7.2 \times 10^{-8}$) and there was a significant difference in GSI between the beginning of the sampling period (1 October to 17 October) and the end (26 November to 19 December; Turkey's test, $P < 0.01$). Correlation analysis indicated there was no relationship between gut fullness (HI) and GSI ($R = 0.12$, $P = 0.4433$).

Table 2 **Mean, standard deviation and range of total length, body weight, gonad weight, and stomach content weight for each sex of Atlantic tomcod collected during September to December 2019 from the Avon and Cogmagun River study sites. Samples from Halfway River were excluded because 19 of the 21 individuals collected were not identified for sex.**

	Total Length (mm) (n = 136)		**Body Weight (g) (n = 136)**		**Gonad Weight (g) (n = 82)**		**Stomach Weight (g) (n = 110)**	
	Male	Female	Male	Female	Male	Female	Male	Female
Avon	(n = 32)	(n = 57)	(n = 32)	(n = 57)	(n = 20)	(n = 35)	(n = 26)	(n = 46)
Mean	199 ± 22	265 ± 34	76 ± 34	149 ± 63	5 ± 3	8 ± 1	1 ± 1	3 ± 2
Range	(170-250)	(210-340)	(141-165)	(62-342)	(0-10)	(0-52)	(0-3)	(1-9)
Cogmagun	(n = 16)	(n = 31)	(n = 16)	(n = 31)	(n = 10)	7 ±5	(n = 17)	
Mean	208 ± 42	235 ± 47	83 ± 44	133 ± 77	7 ±5	12 ±11	2 ± 1	3 ±3
Range	(140-290)	(150-340)	(24-163)	(26-338)	(2-10)	(1-32)	(0-6)	(0-12)

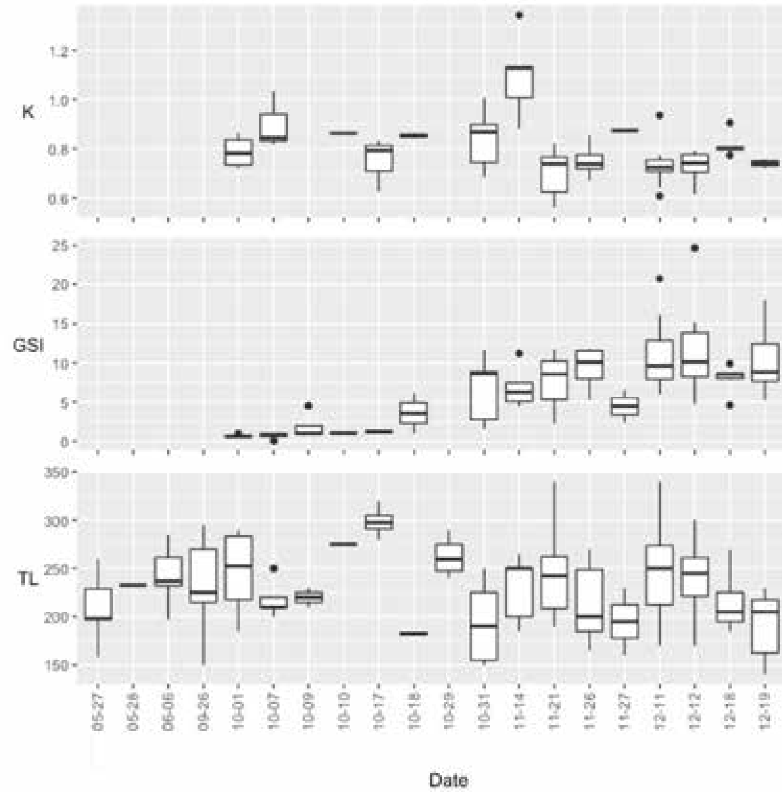

Fig 3 **Condition factor (K), gonadosomatic index (GSI), and total length (TL) distributions for Atlantic tomcod collected during May-December 2019 in the Avon River system of Minas Basin, Nova Scotia. Each box represents the bounds of the 1st and 3rd quartiles; interior dark line is the median, the whisker represents the range, and black dots are outliers.**

DISCUSSION

Stomach contents of Atlantic tomcod were dominated by *Corophium volutator*, an abundant burrow-dwelling amphipod that inhabitants the intertidal mudflats and salt marsh pools in the BoF (Wilson *et al.* 1997, Drolet *et al.* 2013). Tomcod have previously been found to prey on species in direct proportion to their availability and accessibility (Stewart & Auster 1987) suggesting that *C. volutator* are widely available and accessible to benthic feeding tomcod in Minas Basin. *C. volutator* is a key component of the BoF food web and serve as an essential prey item for polychaetes, benthic fish, intertidal invertebrates, and migratory shorebirds (Dadswell *et al.* 1984, McCurdy *et al.* 2005, Hamilton *et al.* 2006, McLean *et al.* 2013).

The Minas Basin Atlantic tomcod study results agreed with similar diet studies in other estuarine regions which also documented tomcod consuming small crustaceans including amphipods and sand shrimp, molluscs, worms, larval crabs, and fish fry (Cox 1921, Salinas 1980, Stewart & Auster 1987). Tomcod apparently gorge themselves when prey is abundant, which was evident from sampling in Minas Basin where stomach fullness was as much as 5.85% of body weight. Tomcod captured by smelt nets in the Miramichi River estuary (Range 25 - 63 mm TL) had gorged themselves on young rainbow smelt approximately 20 mm long, which was half or more of the length of the tomcod that had consumed them (Hanson & Courtenay 2020).

Percent composition of each prey taxa was used to assess diet in this study largely due to time constraints and the digestion state of some prey. For fishes that feed primarily on large prey items, it is usually possible to count all food items in the stomach, however, these analyses are rendered more difficult for smaller fishes feeding on smaller prey and invertebrates (Bowen 1996). Future studies should ensure immediate and adequate preservation of stomach contents to prevent continued digestion and use 10% buffered formaldehyde for preservation rather than 70% ethanol (Bowen 1996) or evaluate stomach contents immediately upon capture.

Results of the diet analysis revealed that Atlantic tomcod in Minas Basin were predominately opportunistic benthic predators. These findings are supported by their functional anatomy since they possess a wide mouth with an inferior lower lip and an extended upper jaw suitable for obtaining prey from the benthos (Cailliet *et al.* 1986). Estuarine fishes are generally recognized as opportunistic, generalist feeders (Selleslagh & Amara 2015) and the extent of consuming certain prey items often depends on their abundance and availability over time and space (Dolbeth *et al.* 2008, de Carvalho *et al.* 2019). Feeding opportunistically allows a fish to change its diet according to environmental conditions and therefore resource availability. This is a key strategy when feeding grounds may only be periodically accessible due to tidal fluctuation (Selleslagh & Amara 2015).

The intertidal mudflat ecosystem in the inner BoF comprises a simple community structure (Polis 1994, Hamilton *et al.* 2006) with a multitude of species reliant on *C. volutator* as their primary source of prey (Dadswell *et al.* 1984, McCurdy *et al.* 2005). The health of *C. volutator*, a low trophic-level deposit feeder, possibly links to the overall health of the Minas Basin ecosystem. *Corophium volutator* are reliant on intertidal mudflats for burrowing habitat, so changes occurring in the sediments of the inner BoF could cause changes to their abundance (Shepherd *et al.* 1995). Alterations from eroding sediment structure could include those that result from increased waterflow caused by storm run-off Boates J.S., (2020, pers. comm.) or anthropogenic structures, such as the Windsor Causeway located in the Avon River (Hamilton *et al.* 2006). Following construction in 1970, fine sediment rapidly accumulated around the causeway that was initially unstable and therefore sub-optimal habitat for *C. volutator*, but the intertidal mud flats were eventually colonized by high densities of *C. volutator* (Partridge 2000). Changes in *C. volutator* abundance because of habitat perturbation could cause a bottom-up trophic effect impacting tomcod abundance as well as distribution (Hamilton *et al.* 2006).

Female Atlantic tomcod examined during this study were significantly larger than males for both total length and body weight, and the difference was not site-specific. This was presumed to be unattributed to differences in age, as most tomcod captured in this study were probably between 2 and 4 years of age based on size (Dadswell *et al.* 1984). The mean and range in tomcod total length found in this study (227 mm, 140-340 mm TL) was similar to tomcod taken in an intertidal weir in Minas Basin (211 mm, 35-380 mm TL; Dadswell *et al.* 2020). The slight difference between these two studies is probably the result of the much larger sample size taken during the weir study.

Female tomcod developed heavier gonads than males which may have contributed to their overall weight differential but GSI's were similar between the sexes. Additionally, there was no correlation between gut fullness and gonad size, suggesting that tomcod do not drastically alter their feeding habits to meet the energy demands associated with the growth and development of gonads before spawning. A similar lack of relationship was also observed for tomcod in Cumberland Basin (Salinas & McLaren 1983), however, in that study it could have been a factor of a temporally small sampling window.

A slight decline in the Atlantic tomcod body condition factor was apparent during the fall study period. The change, however, was not statistically significant. The ten-time increase in GSI found between September to December illustrated the rapid gonad development of tomcod before spawning. But, since there are no other documented condition factor studies that pertain to tomcod, it is difficult to determine if the Minas Basin observation was normal.

This study was the first to examine Atlantic tomcod diet and adult biological characteristics in Minas Basin. Tomcod is apparently an opportunistic predator which targets a wide diversity of prey, especially those with large populations. Any decline of the *C. volutator* population in Minas Basin in the future caused by anthropogenic activities such as climate warming or tidal power development (Hamilton *et al* 2006, Dadswell & Rulifson 2021) could cause trickle down impacts for species such as tomcod by reducing or altering their population and/or habitat usage. Understanding the factors that might influence the abundance of tomcod, both in the present and the future, are key for the conservation of this species. Although no longer fished commercially, tomcod have a food and cultural value for Mi'kmaw communities of Nova Scotia. As well they have a significant ecological value since they could serve as an indicator species for the health of the Minas Basin ecosystem.

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