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Paralytic shellfish toxins in the sea scallop *Placopecten magellanicus* on Georges Bank: Implications for an offshore roe-on and whole scallop fishery

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ABSTRACT

To protect public health from the potential risk of paralytic shellfish poisoning (PSP) in sea scallops, *Placopecten magellanicus*, from the Atlantic offshore U.S. waters of Georges Bank, harvesting of roe-on or whole scallops is banned. Only adductor muscles may be sold if harvested from Georges Bank, Gulf of Maine, or the PSP closure areas as far west as 71° West Longitude. Given the limited toxicity data available for sea scallops from this region both prior to and subsequent to implementation of this management strategy, this study sought a more extensive spatial and temporal evaluation of sea scallop gonad and viscera toxicities that would inform management decisions related to the roe-on and whole scallop fishery. Both overall toxicity and toxin composition were measured for sea scallop gonads and viscera collected from 232 stations in 2007 and 23 in 2010. Overall toxicity was assessed using two screening methods: field-deployable Jellett Rapid Tests (JRT) and quantitative, laboratory-based receptor binding assays (in 2007). Additionally, a quantitative liquid chromatography with fluorescence detection (LC-FD) method was used to determine toxin composition and overall toxicity (in 2010). The at-sea qualitative JRT screening tool results, whereby a positive indicated the sample contained at least 40 μg saxitoxin (STX) equivalents 100 g^{-1}, were often inconsistent with results obtained using the quantitative methods. Sea scallop viscera toxicity represented the majority of toxin load in the organism and was often in excess of the regulatory guidance level. Sea scallop gonads accounted for a small percentage of total toxicity, but at times reached unsafe levels. Toxin composition in both the gonads and viscera was dominated by STX and gonyautoxin 2/3, as has been reported in previous studies. No predictive indices of gonad toxicity were found. Results at this time do not support a roe-on or whole scallop fishery on Georges Bank. While access restrictions to whole scallops on Georges Bank are unlikely to change based on these results, it seems plausible that a management strategy requiring at-sea testing of scallop gonads for PSP may be necessary in order for a safe roe-on scallop fishery from this region to be feasible.

1. Introduction

The sea scallop (*Placopecten magellanicus*) is among the many bivalve species that may serve as a vector for paralytic shellfish toxins (PSTs), the etiological agents responsible for paralytic shellfish poisoning (PSP). The sea scallop adductor muscle, however, has long been shown and considered to be toxin-free and safe for consumption (Medcof et al., 1947; Bourne, 1965; Prakash et al., 1971; Jamieson and Chandler, 1983). In fact, less than 1% of PSP illnesses have been attributed to sea scallops (Prakash et al., 1971), owing to the commercial harvest of adductor only. Thus, the sea scallop industry has not been as impacted by the harvesting closures that have plagued other bivalve mollusc industries. However, roe-on (adductor with gonad attached) and whole sea scallop fisheries have been compromised due to the potential risk of PSP.

Sea scallops can be found in the Atlantic Ocean from off the coast of North Carolina to the Gulf of Maine, with the commercial fishery focused on Georges Bank (Dore, 1991). Separating the Gulf of Maine from the Atlantic Ocean, Georges Bank is an extensive, relatively shallow, highly productive fishing area (~130 × 85 mi) located approximately 100 nautical miles east-southeast of Cape Cod, Massachusetts (MA). According to Dore, sea scallops comprise the bulk of the scallop market in the U.S. where they are sold fresh and fresh-frozen. In the U.S. portion of Georges Bank, only harvesting of sea scallop adductor muscle is allowed; the remaining portions of the scallop must be discarded at sea. Roe-on and

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whole scallop harvest is possible on the Canadian side of Georges Bank, and the Canadian Food Inspection Agency has well-established methods and safeguards in place for the harvest of roe-on and whole scallops (http://www.inspection.gc.ca/food/fish-and-seafood/manuals/canadian-shellfish-sanitation-program/eng/1351609988326/1351610579883?chap=13 (accessed 11.04.13)).

In the U.S., landing whole sea scallops or harvesting tissues other than the adductor from Georges Bank has been banned since 1990 (55 FR 22336, June 1, 1990; 55 FR 35435, August 30, 1990), although a small, artisanal roe-on and whole scallop fishery does exist in Cape Cod Bay, MA, and in other areas within regularly tested state waters. Despite the 1990 closure on Georges Bank and additional closure expansions, notably that implemented in 2005 that moved the line to 71°West Longitude encompassing the Great South Channel and waters surrounding Nantucket Lightship scallop access area, there has been a growing interest by the scallop industry for a roe-on and whole scallop fishery.

Roe-on scallops are popular in the European Union (EU), and it has been estimated that U.S. harvest of roe-on scallops for export to the EU could result in approximately 15% increase in saleable poundage in sea scallops (Day et al., 2007). Further, harvest of whole scallops, as preferred by Asian consumers, would result in sale of the entire live animal at a premium price. Yet, the possibility that PSP toxins (paralytic shellfish toxins or PSTs) may be present in those portions of the sea scallops has prevented such a fishery from developing in U.S. federal waters. It is noteworthy that there are U.S. waters where roe-on and whole scallop harvests are allowed, such as the Mid-Atlantic Bight; however, warm surface temperatures, lack of refrigeration on most vessels, the relatively low roe to meat ratio, and the short time window when prime roe is available, are among the factors that inhibit large-scale roe production from those toxin-free areas.

Anatomical distributions of PSP toxicity in sea scallops collected from the North Atlantic Ocean were described in the 1940s (Medcof et al., 1947). This account also included documentation of the long-term retention of these toxins by *P. magellanicus*. In the early 1960s, PSTs were reported in sea scallop ‘livers’ (i.e., digestive glands or hepatopancreas) collected from Georges Bank, albeit in low concentrations (Bourne, 1965). When Jamieson and Chandler (1983) found essentially toxin-free scallops from three locations on the northeastern ledge of Georges Bank, they recommended that a roe-on scallop fishery on Georges Bank be permitted in Canada. Roe-on scallop harvest from the Canadian portion of Georges Bank was initiated until toxins in excess of the regulatory guidance level of 80 μg saxitoxin equivalents (STX equiv.) 100 g^{-1} were found in scallop gonads in 1989 and 1990, resulting in the closure of this resource during those times (Gillis et al., 1991). The toxicity of the hepatopancreas of these sea scallops measured up to 1440 μg STX equiv. 100 g^{-1}. White et al. (1993a) referenced findings of sea scallop viscera toxicity in the Canadian sector of Georges Bank reaching 7500 μg STX equiv. 100 g^{-1} during that same timeframe. Two sea scallop samplings were subsequently conducted from the American sector of Georges Bank in 1990 and were found to contain up to 14,775 μg STX equiv. 100 g^{-1} (White et al., 1993a). In 1991, whole sea scallop toxicity sampled from two locations on Georges Bank ranged from 66–407 and 40–132 μg STX equiv. 100 g^{-1} (White et al., 1993b). These sporadic and limited samplings represented the extent of knowledge available on sea scallop toxicity of the U.S. Georges Bank sea scallop resource prior to the present study.

In the late 1980s, Cembella et al. (1993) conducted a study investigating PSP toxicity, as well as toxin composition, for inshore and offshore sea scallops, yet both stations were in the Gulf of Maine. They found that digestive glands and mantle tissues accounted for >95% of the total toxin load for both inshore and offshore scallops; however, gonad toxicity did in fact exceed the regulatory guidance level during the investigation, attaining 426 μg STX equiv. 100 g^{-1}. Cembella et al. evaluated their data for quantitative relationships between toxin levels in the different tissue components, but were unable to develop a predictive index of gonad toxicity. In a recent survey that was conducted in parallel to this study, Day et al. (2009) also explored parameters for potential use as predictive indices of scallop gonad toxicity. These included the gonadosomatic index (GSI) and the roe to meat ratio (R/M). The GSI is commonly used to determine the reproductive state of shellfish, and consists of the weight of the roe (gonad) as a fraction of whole animal soft tissue weight. No association was found between the GSI and toxicity. The utility of R/M, if a relationship can be found between this parameter and toxicity, is that it may provide a direct estimate of the increase in saleable poundage possible. Such indices, if found to be predictive, could play a role in improving monitoring and management options for considering a roe-on scallop fishery on Georges Bank.

The primary management strategy for reducing the risk of PSP to public health has been to close bivalve mollusc growing areas to commercial and recreational harvesting when toxins exceed the established guidance level and to ban the harvest of any tissues other than the adductor muscle for sea scallops in certain locations. The present study seeks to improve understanding of spatial and temporal patterns of sea scallop gonad and viscera toxicity on Georges Bank to address the potential for a roe-on and whole scallop fishery. Representing the most extensive investigation of sea scallop toxicity in this region to date, this study includes measurements of overall toxicity and toxin composition in scallop gonads and viscera with extensive coverage on Georges Bank, as well as an evaluation of potential predictive indices for roe-on scallop toxicity. Additionally, the study evaluates the utility of an at-sea screening tool for monitoring sea scallop toxicity in offshore federal waters. These data were gathered within the context of the GOMTOX research program, which focused on the links between surface blooms of *Alexandrium fundyense* and offshore shellfish toxicity and provided supporting evidence of *A. fundyense* blooms, hydrography, and toxicity of other shellfish species on Georges Bank on similar temporal and spatial scales.

2. Materials and methods

2.1. Sample collection

Sea scallop samples were collected from 232 stations on Georges Bank and southern New England waters 24 July–15 August 2007 aboard the R/V *Albatross IV* during the NOAA Fisheries Service Northeast Fisheries Science Center (NEFSC) Sea Scallop Survey. Sample collection was conducted using a modified 8′-wide New Bedford type scallop dredge rigged with a 2 in. diameter ring bag, lined with a 1.5 in. polyethylene stretched mesh liner. Tow duration was 15 min at a speed of 3.8 knots. The average depth from which sea scallops were harvested was 70 m (±16 m). Further information and cruise results are reported at http://www.nefsc.noaa.gov/femad/ecosurvey/mainpage/cruise_results/scallop/2007_scallop.pdf (accessed 10.06.13).

In 2010, sea scallop samples were collected 12–19 June aboard the R/V *Hugh R. Sharp* from 23 stations on Georges Bank, again as part of the NOAA Fisheries Service NEFSC Sea Scallop Survey. Sea scallops were dredged and collected as described above. Samples were harvested from an average depth of 78 m (±12 m). Additional survey information can be found at http://www.nefsc.noaa.gov/femad/ecosurvey/mainpage/cruise_results/scallop/2010_scallop.pdf (accessed 10.06.13).

At each collection site during both surveys, 12 individual sea scallops (when possible) were randomly selected to provide a