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Reproductive biology of the deep-water coral *Acanella arbuscula* (Phylum Cnidaria: Class Anthozoa: Order Alcyonacea), northwest Atlantic

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ABSTRACT

Knowledge of the reproductive life-history of deep-water corals is important for assessing their vulnerability to anthropogenic impacts. Yet, the reproductive biology of many deep-water corals, especially members of the subclass Octocorallia, has not been examined. We used histological techniques to describe the reproductive biology of the deep-water gorgonian coral *Acanella arbuscula* from the northwest Atlantic. All colonies examined were gonochoric, and no embryos or planula larvae were observed in the polyps. Mean polyp-level fecundity (females: 21.0 ± 17.5 oocytes polyp^{-1}, and males: 13.9 ± 13.5 sperm sacs polyp^{-1}) is high compared to other deep-water gorgonians, and polyps closer to the branch tips had the highest fecundities in both females and males. The presence of large oocytes (maximum diameter 717.8 μm) suggests that *A. arbuscula* produces lecithotrophic larvae. Despite the potentially high fecundity and small size at first reproduction, the paucity of information on dispersal and recruitment, combined with its longevity, vulnerability to bottom fishing gear, and ecological role as a structure-forming species, still warrants the classification of *A. arbuscula* as a vulnerable marine ecosystem indicator.

1. Introduction

Over the past few decades there has been substantial research dedicated to the reproductive processes of shallow-water, tropical anthozoans. Egg size, colony sex, polyp-level fecundity, mode of reproduction, and gametogenic cycles have been well documented in this group (for reviews see Harrison and Wallace, 1990; Richmond and Hunter, 1990; Harrison, 2011; Kahng et al., 2011). Much less is known, however, of the reproductive biology of anthozoans found below the photic zone in deeper waters. This is due in part to the logistical difficulties of collecting specimens from the deep ocean and/or subsequent culturing in the laboratory. Within the last decade a number of publications have appeared describing the reproduction of deep-water corals. However, these have mainly focused on reef-building and solitary corals of the Order Scleractinia (Phylum Cnidaria: Class Anthozoa: Subclass Hexacorallia) (e.g., Waller et al., 2002,2005,2008; Waller, 2005; Flint et al., 2007; Waller and Tyler, 2010; Mercier et al., 2011). Despite their diversity and ecological significance in deep waters, reproductive studies of members of the Subclass Octocorallia (Phylum Cnidaria: Class Anthozoa) are scarce. Much of our current knowledge of deep-water octocoral reproduction is based on a few studies of Antarctic gorgonians (Brito et al., 1997; Orejas et al., 2002, 2007), and on members of the Order Pennatulacea (Phylum Cnidaria: Class Anthozoa) (Rice et al., 1992; Tyler et al., 1995; Eckelbarger et al., 1998; Pires et al., 2009).

Octocorals, and anthozoans in general exhibit two modes of sexual reproduction: Internal fertilization and brooding of planula larvae; and broadcast spawning with external fertilization of gametes. Brooding may occur in one of two ways: internally in the gastrovascular cavity or siphonozooids of some species (Cordes et al., 2001; Waller and Baco, 2007), or on the surface of the colony (Benayahu and Loya, 1983; Brazeau and Lasker, 1990; Coma et al., 1995; Gutiérrez-Rodríguez and Lasker, 2004). The mode of sexual reproduction is variable within the majority of orders in the Octocorallia, with only members of the Order Pennatulacea observed sharing the same reproductive mode of broadcast spawning (Chia and Crawford, 1973; Rice et al., 1992; Tyler et al., 1995; Eckelbarger et al., 1998; Edwards and Moore, 2008, 2009; Pires et al., 2009). In general, gorgonian corals display similar proportions of internal brooders, external brooders, and broadcast spawners (Ribes et al., 2007). Both hermaphroditism and gonochorism occur in gorgonians, but in contrast to the Scleractinia (Harrison, 2011), gonochorism is more prevalent (Ribes et al., 2007).

At least 45 species of deep-water coral occur on the Canadian margin of the Atlantic Ocean (Cogswell et al., 2009). A large portion of these are members of the subclass Octocorallia. Despite the high diversity and abundance of octocorals in this region, the

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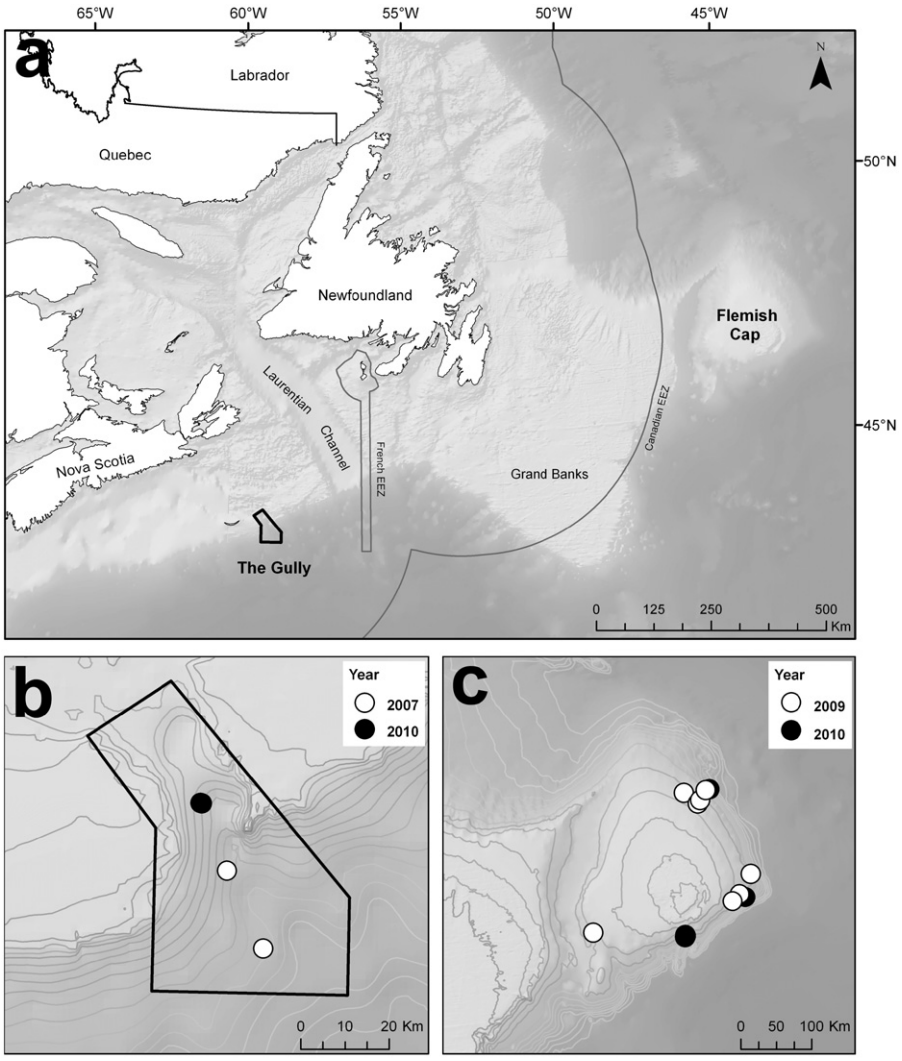

Fig. 1. (**a**) Map of eastern Canada showing the location of The Gully MPA and Flemish Cap. EEZ is exclusive economic zone; French EEZ represents Saint-Pierre et Miquelon. (**b**) *A. arbuscula* sampling locations in The Gully during 2007 (white circles) and 2010 (black circles). (**c**) *A. arbuscula* sampling locations in the Flemish Cap area in 2009 (white circles) and 2010 (black circles). Depth contour intervals are 50 m until 200 m; 200 m intervals thereafter. Actual depth of sampling locations is available in Table 1.

reproductive biology of only a few of them has been documented (see Sun et al., 2010a,2010b,2011; Mercier and Hamel, 2011). These studies have focused primarily on soft, fleshy corals, and not on sea fans (gorgonians).

Here, we focus on the reproductive biology of the small branching coral *Acanella arbuscula* (Johnston, 1862) of the family Isididae, Order Alcyonacea (Phylum Cnidaria: Class Anthozoa). We chose this species because of its relatively high abundance and wide distribution in the North Atlantic, and because it is recognized as a vulnerable marine ecosystem (VME) component (to bottom fishing gears) by the Northwest Atlantic Fisheries Organization (NAFO) (Fuller et al., 2008), and therefore of conservation concern. *A. arbuscula* is distributed in the northwest Atlantic from the Davis Strait (Kenchington et al., 2010) and Greenland (Deichmann, 1936; Grasshoff, 1981), down the eastern seaboard of North America to Cape Hatteras (Watling and Auster, 2005), the Gulf of Mexico (Brooke and Schroeder, 2007) and southeast Brazil (Arantes et al., 2009). It is also found in the northeast Atlantic (Lawson, 1991), from Iceland to the Mid Atlantic Ridge (Grasshoff, 1981; Mortensen et al., 2008) and Morocco (Molodtsova et al., 2008). This species inhabits soft sediments in the northwest Atlantic and has an overall depth range of 150–4800 m (Molodtsova et al., 2008; Kenchington et al., 2009).

Aspects of the biology of *A. arbuscula* have previously been described. Sherwood and Edinger (2009) estimated the age and growth rate of this species. The reproductive biology was described by Lawson (1991), who predicted that *A. arbuscula* from station 'M' (57°18′ N, 10°11′ W) in the northern region of the Rockall Trough, northeast Atlantic (Gage and Tyler, 1982), was a brooder based on its large egg size and gamete developmental cycles, although planula larvae were not observed. Lawson (1990 in 1991) also suggested there was no variability in the reproductive output from different areas of the same colony, which contrasts the findings of many studies that have examined intra-colony variation in reproduction in octocorals (e.g., Coma et al., 1995; Brito et al., 1997; Orejas et al., 2002,2007; Santangelo et al., 2003; Gutiérrez-Rodríguez and Lasker, 2004; Pires et al., 2009).

Our objectives were to: (1) describe the general features of *A. arbuscula's* reproduction, including colony sexuality, mode of sexual reproduction, and gametogenesis; (2) investigate intra-colony variation in polyp-level fecundity, oocyte diameter, and spermatic development; and (3) determine a minimum size at first reproduction and the relationship between colony size and polyp-level fecundity. The use of histology allows us to present the first account of the gametogenic stages in this species. We augment knowledge of the general reproductive biology of