ARROW WORM

Sagitta elegans Verrill, 1873
(Sagittidae)

Global rank GNR – recommended change to G5 (08Jul2005)
State rank S5 (08Jul2005)
State rank reasons
Widespread and abundant in nearshore coastal waters. An important component of marine planktonic communities. Threatened by pollution to the marine environment as a result of oil spills, sewage dumping, industrial runoff, or contamination from mariculture practices.

Taxonomy
Taxonomy unclear; some authors have divided genus *Sagitta* into different genera and included this species in *Parasagitta* instead of *Sagitta* (Tokioka 1965, Bieri 1991, see Terazaki 1998). Three subspecies recognized: *S. e. elegans*, *S. e. arctica* and *S. e. baltica*; they differ in maximum body length, number of hooks and teeth, and length of ovaries. The entire phylum Chaetognatha, known as arrow worms or chaetognaths, is marine and consists of about 100 species (Brusca and Brusca 1990).

General description
A large transparent zooplankton shaped like a torpedo or arrow; mature adult body length usually around 20-30 mm. Nine to 11 unserrated grasping spines on the sides of the head are used to capture and ingest other zooplankton prey; spines covered with a hood while swimming. Eyes small, each with a round pigment spot. Body firm in comparison to other chaetognaths (but chaetognaths in general are soft-bodied, almost gelatinous), with distinct head, trunk and tail segments. Anterior lateral fins shorter than and well separated from posterior lateral fins (Kozloff 1987, Todd et al. 1996).
Length (cm) range 20-30; max. 36

Reproduction
Chaetognaths are hermaphroditic, with paired ovaries in the trunk and paired testes in the tail; each individual produces both eggs and sperm (Brusca and Brusca 1990). Self-fertilization probably does not occur; instead, mating is believed to occur when two individuals exchange sperm packets and ova are fertilized internally (Brusca and Brusca 1990, Todd et al. 1996). Eggs released as fertilized zygotes (coated in a jelly-like substance); development is direct and lacks any larval stage or metamorphosis; from egg release to hatching is rapid, probably within 48 hours (Brusca and Brusca 1990). Number of eggs per ovary ranges from 30-1,000 (McLaren 1966). Adults may spawn once or several times over a period of months, then die shortly thereafter. Spawning periods are variable: in coastal waters off southern Hokkaido, Japan, spawning was observed in April-June, while in the southern Japan Sea two spawning periods have been observed, in March-May and also later in August (Terazaki 1998). Dunbar (1941) observed a single spawning period for this species in the western Atlantic, from June-July through October. Number of broods produced per year increases with distance from the North Pole; one brood annually in arctic-subarctic waters (Kramp 1939 in Terazaki 1998); 2 to 5 broods near southern boundary of distribution in temperate regions (Dunbar 1941, Terazaki 1998). Life span estimated at one (Alvarez-Cadena 1993a, Terazaki 1998) or two years (Dunbar 1962, Welch et al. 1996), depending on latitude of occurrence within range. Welch et al. (1996) reported *S. elegans* grew during winter and presumably fed continually year-round despite water temperatures as low as -1.8°C in the Canadian arctic.

Ecology
Arrow worms are an important and abundant part of the marine food chain of oceans of the Northern Hemisphere; in general, chaetognaths often rank second in abundance to copepods among all marine zooplankton groups. May compete with fish larvae for their primary food, copepod zooplankton (Baier and Purcell 1997). Larval and juvenile forms preyed upon by many higher trophic level planktivores (Robards et al.

2003) and fishes including walleye pollock (*Theragra chalcogramma*) and herring (*Clupea* spp.; Brodeur and Terazaki 1999).

Chaetognaths alternately swim and float, with fins acting as flotation devices; when the body begins to sink, trunk muscles contract rapidly and the animal darts swiftly forward. The same movement is used to capture prey (Barnes1987).

Migration and phenology
There is no consensus on the diel vertical migration of *S. elegans*. Some investigators have observed typical diel migration by adults (i.e. found near surface at night and in deeper waters during the day) (Nishiuchi et al. 1997, Terazaki 1998) but not by immature individuals (Choe and Deibel 2000). Brodeur and Terazaki (1999) described an inverse diel migration pattern for juveniles, with higher abundance near the surface during the day. These patterns likely follow changes in light levels or vertically migrating prey. Average speed of upward and downward migration has been recorded as 30 meters/hr in adult individuals in the Japan Sea (Terazaki 1998).

Food
Primary food is small copepod zooplankton including *Pseudocalanus* spp., *Metridia pacifica*, *Neocalanus* spp. and *Oithona* spp. (Alvarez-Cadena 1993b, Terazaki 1998, Brodeur and Terazaki 1999). Will secondarily consume other small zooplankton including barnacle nauplii and larval stages of euphausiids, occasionally cannibalistic upon smaller individuals, and will also eat herring larvae (Alvarez-Cadena 1993b). Arrow worms are raptorial ambush predators; will remain still using mechanoreceptors that sense water movements to detect prey, then dart forward to grab and ingest organisms using grasping spines on either side of the head. Some chaetognaths may also inject a potent neurotoxin called tetrodotoxin into prey (Brusca and Brusca 1990).

Habitat
A marine species; most abundant near shore (Bieri 1959). Typical of the upper 100 to 150 m of the water column in arctic and subarctic regions, but also occurs in the mesopelagic layer to around 1,000 m (Terazaki 1998). In recent studies it was also found in the benthic zone near the ocean floor (Brodeur and Terazaki 1999, Choe and Deibel 2000). Eurythermal; reported at water temperatures ranging from -1.5 to 21.0°C (Alvarino 1965), although growth and mortality rates may be greatest between 1.0 and 12.0°C (Sameoto 1966). Distribution thought to be limited to water with oxygen concentrations of at least 6 ml/l (Alvarino 1964 in Marumo 1966); however, in Sagami Bay, North Pacific Ocean, *S. elegans* were found in deep water with oxygen concentrations less than 4 ml/l (Marumo1966). Generally occur at salinities around 32 to 33 pph (Sund 1959, Welch et al. 1996).

Global range
Widespread throughout the Arctic, North Pacific and North Atlantic regions; in the Pacific occurs as far south as the southern Japan Sea and the south coast of British Columbia, in the Atlantic south to the coast of Maine and north coast of Spain. The southern boundary of distribution is about 40 to 41° N (Bieri 1959, Van der Spoel and Heyman 1983). Bieri (1959) suggested distribution in the Pacific is limited to the subarctic water mass.

State range
Beaufort, Chukchi, and Bering Seas, throughout the Aleutian Islands and Gulf of Alaska including the Alaska Peninsula, Lower Cook Inlet, Prince William Sound, and in waters surrounding and south of Kodiak Island; also in Southeast Alaska in Glacier Bay (Sund 1959, Redburn 1974, Cooney 1975, Wing and Hoffman 1976, Brodeur and Terazaki 1999, Robards et al. 2003).

Global abundance
Generally abundant, often the most common predatory zooplankton species collected during surveys and a major contributor to total zooplankton biomass throughout its range.

Abundance estimates vary by location, season, and survey method. In the eastern part of the Bering Sea, highest abundance reported was 25 individuals/m^3; also abundant off the eastern coast of Kamchatka near the Kuril Islands (0.5-1.5/m^3 in the Kuril-Kamchatka trench; see sources in Marumo 1966) and Hokkaido, Japan; relatively abundant in southern coastal waters along the Aleutian Islands, Alaska (Terazaki 1998). In the North Sea, near Great Britain, abundance was 13 individuals/m^3 (Clark et al. 2003) and 191 individuals/m^2 at Resolute Passage in the Canadian High Arctic (Welch et al. 1996). Other abundance estimates include 0.5-3.2/m^3 in the Pacific Ocean east of Japan (Kitou unpubl. in Marumo 1966) and 0.2-2.8/m^3 in the Subarctic Current System of the northern North Pacific

(Nishiuchi et al. 1997). Bieri (1959) reported highest relative abundance near shore in the Pacific Ocean, and decreases in abundance as the pack ice was penetrated.

State abundance
Generally abundant, often the most common predatory zooplankton species collected during surveys and a major contributor to total zooplankton biomass. Abundance estimates vary by location, season, and survey method. In surveys conducted throughout the Gulf of Alaska, abundance ranged from 0.06-0.9 individuals/m^3 (Brodeur and Terazaki 1999). Maximum reported abundance from Glacier Bay was 50 individuals/m^3 (Robards et al. 2003); 24 individuals/m^3 in the Chukchi Sea near Point Barrow (Redburn 1974); and around 100 individuals/m^2 in Prince William Sound (Cooney 1975).

In the Gulf of Alaska, Sund (1959) reported highest relative abundance generally south of Kodiak Island, while another study found higher abundance at continental slope compared to continental shelf stations near Kodiak Island (NMFS 1980). Highest relative abundance in Lower Cook Inlet reported during the winter (November to February; Wing and Hoffman 1976), but studies elsewhere in Alaska (Glacier Bay; Robards et al. 2003, Chukchi Sea; Redburn 1974) report highest abundance in May and June.

Global trend
Unknown.

State trend
Unknown.

Global protection
Unknown.

State protection
No official protection for this species in Alaska.

Global threats
Possible threats include pollution of marine habitats from oil spills, sewage dumping, forestry and mining runoff, and introduction of pesticides from mariculture and agricultural activities. Climate change may pose an indirect threat by altering primary productivity and the production of zooplankton prey species; temperature is also linked directly to this species' growth rate and generation time (Oresland 1985, Oresland 1986 in Clark et al. 2003). General lack of knowledge about factors that may limit population growth (e.g., habitat conditions, prey availability, predation pressure) may pose a threat to management of zooplankton populations.

State threats
Possible threats include pollution of marine habitats from oil spills, sewage dumping, forestry and mining runoff, and introduction of pesticides from mariculture and agricultural activities. Marine oil spills are a potential threat in Alaska, but because this species occurs in the water column as opposed to surface waters it may be less impacted by oil slicks than other marine animals. Pesticides applied to mariculture crops may harm invertebrates other than those targeted, and their impacts on *S. elegans* are unknown.

See Global threats for comments on the effects of climate change.

State research needs
Research needed on the trophic significance of arrow worms in diets of forage fishes, commercially harvested fishes, and sea birds. Determine if pesticides used in mariculture practices are harmful to *S. elegans* and associated prey species. Study factors that may be limiting to population growth including habitat characteristics, prey availability, and predator pressure; examine potential effects of increased water temperatures as a result of climatic warming.

State inventory needs
Monitor abundance temporally and spatially; develop a long-term monitoring program to survey sites throughout Alaska similar to the monitoring program developed by the California Cooperative Oceanic Fisheries Investigations (see CalCOFI 2004).

State conservation and management needs
Protect marine habitats from pollution and the introduction of pesticides from mariculture and agriculture while researching the potential effects of these and other threats. Develop and establish a long-term monitoring plan for zooplankton populations in Alaskan waters using protocols established by CalCOFI as a model (see State inventory needs).

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