Distribution of a pelagic tunicate, *Salpa fusiformis* in warm surface current of the eastern Korean waters and its impingement on cooling water intakes of Uljin nuclear power plant

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**Abstract:** Impingement of a large amount of gelatinous plankton, *Salpa fusiformis* on the seawater intake system screens in a nuclear power plant at Uljin was firstly recorded on 18th June 2003. Whole amount of the clogged animals was estimated at 258 tons and the shortage of cooling seawater supply by the animal clogging caused 38% of decrease in generation capability of the power plant. Zooplankton collection with a multiple towing net during the day and at night from 5 to 6 June 2003 included various gelatinous zooplanktons known to be warm water species such as salps and siphonophores. Comparatively larger species, *Salpa fusiformis* occupied 25.4% in individual density among the gelatinous plankton and showed surface distribution in the depth shallower than thermocline, performing little diei vertical migration. Temperature, salinity and satellite data also showed warm surface current predominated over the southern coastal region near the power plant in June. The results suggested that warm surface current occasionally extended into the nertic region may transfer *S. fusiformis*, to the waters off the power plant. The environmental factors and their relation to ecobiology of the large quantity of salpa population that are being sucked into the intake channel of the power plant are discussed.

**Key words:** *Salpa fusiformis*, Depth distribution, Power plant impingement, Cooling water intakes

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**Introduction**

Marine zooplankton and fish are often unevenly distributed, forming high density of the animal aggregation of patches, shoals, swarms and schools. Because of these distributional characteristics, mass amount of various marine organisms has been accidentally sucked in cooling-water intakes at nuclear power plants located in the eastern coast of Korea where huge amount of seawater, approximately 30-60 tons sec−1 per power station, is provided into condensers (Lee et al., 2005). The animal impingement has often clogged filter screens to cause temporal interruptions of electric power generation because the screen dog is a serious obstacle to the cooling seawater supply (Sonny et al., 2006).

According to records of interruption of electricity generation by marine animal impingement on the intakes of Uljin nuclear power plant (NPP), euphausiids, *Euphausia pacifica* and moon jellies, *Aurelia aurita* have been the main organisms to clog frequently drum screens in the cooling water supply system since 1996 (Lee et al., 2005). Uljin NPP informed us a large amount of ‘jelly-like animals’ or ‘jellyfish-like animals’ clogged the drum screens and they had to decrease output of power generation by 38% in 18th June 2003. Korea Hydro and Nuclear Co. estimated presumptively the whole amount of the clogged animals removed as 258 tons (Lee et al., 2005). The animals clogged on the screens were identified through this study as a pelagic tunicate, *Salpa fusiformis*, and recorded as the first incidence of impingement by this species. The amount of the other marine organisms, euphausiids, moon jellyfish and anchovy clogged the drum screens when power generation interrupted, has ranged between 129 tons (May 1999) - 217 tons (May 2001), 132 tons (Jan. 1998) - 5100 tons (Aug. 2001), and 247 tons (May 1999) - 294 tons (Feb. 2004), respectively (Lee et al., 2005). Compared to these records, *S. fusiformis* is found to be a significant marine organism to clog the intake screens.

Time-seral investigation of depth distribution of zooplankton with a multiple horizontal net tow was made in the waters off the power plant on 5-6 June 2003, two weeks before the salpa impingement. We also examined the individuals from the sub-samples of the clogged animals from the intakes. Those results were compared to NOAA’s sea surface temperature (SST) image data, temperature, salinity profiles and chlorophyll concentration, and then relationships of distribution of *Salpa fusiformis*, environmental characteristics and impingement on cooling water intakes of Uljin nuclear power plant were discussed.

**Materials and Methods**

The day after accident of screen clogging by mass impingement of gelatinous zooplankton onto the intakes of Uljin NPP on 18th June 2003, live samples of salps in the intake channel were collected, while directly removed from the clogged screens samples were significantly damaged and could not be identified. Since individuals in the intake channel were not distributed as in natural condition because of artificial obstructions such as protection nets and trash bars, and the water movement interfered by pumping...
SST data was used. A CTD profiler (Seabird 19, USA) and chlorophyll close mechanism (General Oceanics, USA) in the waters off the forms were measured.

Body lengths of the individuals of both the aggregate and solitary forms were measured.

On 5-6 June 2003, two weeks before the intake impingement of salps, zooplankton depth distribution was investigated using nets (0.6 m diameter and 300 μm mesh aperture) with a close-open-close mechanism (General Oceanics, USA) in the waters off the nuclear power plant. Samples were collected from discrete depths of 5 m near-surface, 10 m, 20 m, 30 m, 40 m, and near-bottom (approx. 50 m) with 1-3 hr intervals from 18:00 on 4 June to 20:00 on 5 June. Temperature and salinity profiles were measured using a CTD profiler (Seabird 19, USA) and chlorophyll a concentration were determined with spectrophotometric (Hewlett Packard, G1103A, Germany) measurement (Parsons et al., 1984) at four stations (Fig. 1).

To understand the relationship of occurrence of high density of the salps and hydrographic conditions in the region, NOAA's SST data was used.

Results and Discussion

Samples of gelatinous animals collected from the intake channel the day after the screen-clogging by the impingement of

<table>
<thead>
<tr>
<th>Species</th>
<th>% of ind of species / total gelatinous plankton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salps</td>
<td></td>
</tr>
<tr>
<td>Salpa fusiformis</td>
<td>25.4</td>
</tr>
<tr>
<td>Thalia demorctica var. orientalis</td>
<td>4.6</td>
</tr>
<tr>
<td>Dololcium denticulatum</td>
<td>11.4</td>
</tr>
<tr>
<td>Dololcium nationalis</td>
<td>2.4</td>
</tr>
<tr>
<td>Siphonophores</td>
<td></td>
</tr>
<tr>
<td>Diphyes chamissonis</td>
<td>42.1</td>
</tr>
<tr>
<td>Muggiaea sp.</td>
<td>3.7</td>
</tr>
<tr>
<td>Hydromedusae</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Net collection made on 4-5 June 2003 involved various sub-tropic and tropic species of salps and siphonophores, with some other unidentified hydromedusae (Table 1). While a siphonophore, Diphyes chamissonis occurred with the highest individual density, the body size of individuals may not be large enough to clog the drum screen or form no strong patchiness to let mass amount of the animals enter into the intake screens. Salpa fusiformis, comparatively large size species, occupied 25.4% in individual density among the cridarian and tunicate plankton. Thalia demorctica was the other large size species which can clog the screen, and may be the most abundant in the Kuroshio current waters, however showed only low density in this study, and was
Fig. 3: Distribution of Salpa fusiformis in eastern Korean waters. Fig. 4: TS profiles and chlorophyll a concentration in 4-5 June, 2003. Dotted lines and solid lines indicate temperature and salinity, respectively.

Fig. 3: TS profiles and chlorophyll a concentration in 4-5 June, 2003. Dotted lines and solid lines indicate temperature and salinity, respectively.

Fig. 4: Diel change of depth distribution of Salpa fusiformis in 4–5 June, 2003.
not found in cooling water intake channel, either on 18th June 2003. During the sampling period, *S. fusiformis* showed shallow distribution in the depth of surface mixed layer, showing no conspicuous DVM (diel vertical migration, Fig. 3, 4). Higher individual densities of the animals were collected usually at night, while unfortunately only a little amount of samples were collected especially during the daytime, possibly because of strong trend of patch distribution of the species (Brattstrom, 1972).

Salps are in general known to be widely, but sparsely distributed, and the most species scarcely occurring in neritic environments (Kashkina, 1978). However, they often show patchy distribution, and in cases, aggregate as swarms what is called ‘intermittent blooming’ (Brattstrom, 1972). Rapid growth of salp population may be achieved due to the asexual reproduction of solitary individuals which produce aggregate zooids by budding. Each individual of this aggregates is hermaphroditic, and again sexually reproduce solitary by fertilization (Aldredge and Madin, 1982). Occurrence of high density of the alternation of generation of *Salpa fusiformis* in this study suggested that the animals could attain rapid population increase through the ontogenic cycle.

Blooms of salps have been reported widely from several parts of the world oceans and seas, but the adequate conditions that support the blooms are not well understood. However, hydrographic conditions where the high abundance of *Salpa fusiformis* has been recorded can be recognized as upwelling (Blackbum, 1979; Le Borgne, 1983; Harris et al., 1991; Menard et al., 1994) and fronts of warm core ring (Bradford and Chapman, 1988; Tsuda and Memoto, 1992). The blooming also has been usually observed during spring and summer when the phytoplankton is productive (Blackbum, 1979; Harris et al., 1991; Menard et al., 1994). High density of salps, *Thalia democratica* and *S. fusiformis* observed in a warm-core ring in the Kuroshio Current was observed near the surface and in deeper layer respectively, and each of the depths were chlorophyll maximum layers, too (Tsuda and Nemoto, 1992). These reports suggested that the alternation of generation of salps may be achieved when enough food sources are provided to these animals, and the growth rates are extremely high (Heron and Benham, 1984; Le Borgne and Moll, 1986; Laval, 1997).

Maximum concentrations of chlorophyll a reported at the same stations were below 0.8 μg l⁻¹ in Oct. 2002 and 0.2 μg l⁻¹ in Dec. 2002, Jan. and Mar. 2003 (Lee et al., 2005). Chlorophyll a concentrations in 4-5 June were much higher than those of other seasons, ranging from 1.31 μg l⁻¹ to 3.60 μg l⁻¹ in maximum, and the maximum depths were observed about at 10 m depth in mixed layer where *Salpa fusiformis* was distributed (Fig. 3). Although this study showed snap-shot data collected only at the time of the event of salpa impingement and direct hydraulic measurement was not made, Temperature, salinity profiles and satellite data showed East Korean Warm Current (EKWC) predominated over the southern coastal region near the power plant in June, forming boundary line with cold water flow from the north (Fig. 5). The results suggested
that EKWC characteristically extended into the neritic region may transfer the warm water species, and then high production of phytoplankton in ambient waters probably let S. fusiformis reach or maintain high abundance. As mentioned above, fronts, upwelling, and convergence of hydrographic condition especially lead to distributional integration of tunicates (Paffenhofer and Lee, 1987; Tsuda and Nemoto, 1992), thus the extension of the current into the area off the nuclear power plant may be deeply concerned to the intake impingement of S. fusiformis.

Figure 6 summarizes directional frequency and mean speed of the upper layer from ADCP (acoustic doppler current profiler) data observed bimonthly during 5 years from 2000 to 2005 by National Oceanographic Research Institute in Korea (Choi and Kim, 2006). The numbers off Uljin indicate the median points of each ADCP tracking lines. Northward surface current had been the most generally observed pattern (42% in frequency) with the highest speed. The northwestward one, which may lead to neritic extension of the upper layer from ADCP (acoustic doppler current profiler) fences (Ross won (134,000 US dollars approximately) according to price criterion.

Twenty-eight times of obstruction to electric generation of Uljin NPP by marine-animal impingement had been recorded from 1992 to 2005, causing economic loss equivalent to 17,372 million won (17.8 million US dollars approximately, Lee et al., 2005; Korea Hydro and Nuclear Co., personal communication). The major impingement organisms had been euphausiids, jellyfish, and anchovy, while salps were firstly reported in this study as the organism hampered the intake screens by clogging. Salp impingement on the cooling water intakes on 18th June 2003 caused 38% of decrease in generation capability of the power plant during 10 hr approximately with loss of 3,350 MW of electric generation (Lee et al., 2005). It is equivalent to economic loss of 130 million won (134,000 US dollars approximately) according to price criterion of the electric supply by Korea Hydro and Nuclear Co. and amount of 100 % of electricity generation by the NPP. Electrical screens, bubble curtains, artificial light arrays (Hadderingh, 1982; Hadderingh et al., 1988; 1992; Welton et al., 2003) and underwater acoustic fences (Ross et al., 1996; Popper and Carlson, 1998; Sonney et al., 2006) have been suggested to be behavioral barriers for fish protection to induce an avoidance response away from a water intake. Photo-response of euphausiids was tested near Uljin NPP for using artificial light source to induce the animals away from the cooling water intakes (Chae and Lee, 2005), however any behavioral barriers for salps has not been made. A newly developed intake screens or other technique may be needed to be tested for salps as well as for euphausiids, jellyfish and anchovy in the waters near cooling water intakes of the Uljin NPP (Lee et al., 2006).

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References


