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A Study of the Temperature Tolerances of Adult *Solen rosaceus* and *Tagelus californianus* in South San Diego Bay: The Effects of Power Plant Cooling Water Discharge

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INTRODUCTION

The San Diego Gas & Electric Company operates a fossil-fuel electric generating station at the southern end of the San Diego Bay. Daily it discharges heated effluent into the bay proper which results in extreme water temperature fluctuations in the vicinity of the cooling channel that are influenced by season, power demand, and tidal level. The mudflats several kilometers to the north are free of this man-made perturbation and represent a more stable environment with a predictable seasonal component.

The San Diego Gas & Electric Company began operation of the South Bay Power Plant in 1960. By the summer of 1964 three generating units were operating, with a maximum power generation capacity of 250 MW. A larger, fourth unit was completed in 1971, bringing the total maximum generating capactiy to [illegible] MW. With the addition of the fourth generating unit, the maximum horizontal extent of the thermal plume increased from approximately 1800 m to 2700 m beyond the end of the cooling water channel (Chambers and Chambers, 1973). With four generating units in operation, the average temperature rise (t) between the points of intake and discharge for the cooling water was $7^{o}C$; the average discharge volume was $16x10^{5}$ liters (420,000 gallons) per minute (A. DeWeese, SDG&E, personal communication).

Studies by Ford (1968), Ford et al. (1970, 1971, 1972) and Ford and Chambers (1973, 1974) describe the physical environment and marine benthic communities of inner San Diego Bay before and during operation of the fourth generating unit. These studies employed data on species composition, species diversity, distribution, abundance, and biomass to evaluate thermal effects. One result of the studies indicated that some clam species, such as the smooth cockle (*Chione fluctifraga*) and the California jackknife (*Tagelus californianus*), were more tolerant of warm water conditions associated with the thermal plume than were others, such as the pencil clam (*Solen rosaceus*). Their patterns of distribution and abundance in the area appeared to reflect these differences in temperature tolerance.

STATEMENT OF THE PROBLEM

Based on this evidence, I selected two species for a more detailed, comparative study of population characteristics at representative locations within and outside the area influenced by the thermal plume. These were the pencil clam, *Solen rosaceus* Carpenter, 1864 and the California jackknife clam, *Tagelus californianus* [Conrad, 1837]. In terms of their abundance and size, both are dominant members of the benthic community at the inner end of San Diego Bay.

It is clear that species populations respond to a complex set of environmental factors. Within inner San Diego Bay, these important environmental factors include both physical and chemical characteristics of the water and sediments, and biological interactions such as feeding, competition and predation. The distribution and abundance of most intertidal invertebrates are known to be affected by these factors (Maurer, 1969; Frank, 1965, Kenzler, 1967; Ford, 1968; Sameoto, 1969; Woodin, 1974; Holland & Dean, 1977a).

The manner in which both environmental and biological factors change and interact over time may strongly influence the population characteristics of a particular species, and ultimately its life-history features (Gadgil & Bossert, 1972; Stearns, 1976; Brown, 1979).

Prior to this study, very little was known about the population characteristics of *S. rosaceus* and *T. californianus* or the physical and biological variables affecting them. I am not aware of any published information which discusses the population dynamics of either species, although some information exists for T. plebius and T. divisus on the Atlantic Coast of the United States. (Holland and Dean, 1977a,b; Bloom, Simon & Hunter, 1972).

The objectives of this study are to: a) describe the physical environment in which both species exist; b) describe their distribution and dispersion patterns; c) describe their various population characteristics; d) evaluate the possible factors regulating these populations in both the natural and thermally altered environments; e) describe the effects of increased temperature by laboratory and field studies on observed patterns of growth, reproduction and longevity in the natural and thermally altered environments.

The question is whether the elevated water temperatures in the vicinity of the cooling water channel are sufficient to change distribution and abundance patterns, and the population characteristics of S rosaceus and T. californianus in the thermally altered environment.

Characteristics of Solen rosaceus and Tagelus californianus

Solen rosaceus occurs in bays and estuaries from Santa Barbara, California to Mazatlan, Mexico (Keen, 1971), a very limited distribution of about 10^o latitude, not reaching tropical waters. Other species of Solen occur in the colder waters off Japan. Mature individuals reach a maximum shell length of 70 mm (McLean, 1969). Large individuals I have taken in San Diego Bay measured 60–85 mm in maximum shell length. This species has an elongated, tubular shell that is thin and fragile. The beak is near the anterior end and the shell gapes anteriorly and posteriorly.

The burrows of S. rosaceus may extend to a depth of 25–30 cm in the sediment. Individuals normally maintain a position in the upper 5–10 cm of the sediment, with the united siphons held at the mud-water interface. When disturbed or out of the burrow, an individual can re-enter the sediment rapidly. If sufficiently disturbed it sheds siphonal rings, a characteristic that apparently affords protection against predation by shorebirds and demersal fish. Solen rosaceus appears to be a suspension feeder, as are other members of the razor clam family, Solenidae.

Tagelus californianus is a common mudflat species in bays and estuaries from Humboldt Bay, California to Panama (McLean, 1969). This wider geographical range than that exhibited by S. rosaceus might be expected to contribute a greater range of temperature tolerance to T. californianus. The reported size range of mature individuals is 60–120 mm. In San Diego Bay the largest individual I measured during this study was 110 mm. The shell of T. californianus is heavier and larger than that of S. rosaceus. It is also more elongated, with the ventral and dorsal margins nearly parallel and the beak more centrally located. Like that of S. rosaceus, the shell of T. californianus also gapes anteriorly and posteriorly.

Tagelus californianus maintains an intermediate position in its burrow at depths of 10-15 cm below the sediment surface, with the separate inhalant and exhalant siphons held at the mud-water interface. *Tagelus californianus* is also a suspension feeder (Pohlo, 1973). Members of this family extend their siphons to feed on suspended deposits on the sediment surface.

DESCRIPTION OF THE STUDY AREA

The control study area north of the South Bay Power Plant is a natural mudflat, and one of the few original sites of this kind remaining in San Diego Bay. It is located approximately 3.5 km north of the San Diego Gas & Electic Company cooling water channel of the South Bay Power Plant (Figure 1). This intertidal mudflat was formed and is maintained by the accumulation of silts and sands deposited by the Sweetwater River. Median grain size values for the control area were fairly uniform during the study period, ranging from 0.10–0.13 mm. Greater variability existed in median grain sizes on mudflats in the test area, with values ranging from 0.10–0.60 mm. This greater variability probably is due primarily to natural deposition by tidal action, and to dredging and filling activities during construction of the earthen dike.

Seasonally, algae of the genera *Gracilaria*, *Enteromorpha*, *Cladophora*, and *Ulva* form extensive mats over the sediment surface. Below Mean Lower Low Water (MLLW) *Gracilaria verrucosa* and the bryozoan, *Zoobotryon verticillatum* are common; while the above algal genera are dominant primarily in the intertidal areas. The most common large mudflat animals in the study areas are mudflat crabs (*Hemigrapsus oregonensis*), California hornshells (*Cerithidea californica*), mud dog whelks (*Nassarius tegula*), smooth cockle clams (*Chione fluctifraga* and *C. undatella*), California jackknife clams (*Tagelus californianus*); pencil clams (*Solen rosaceus*), and tellins (*Tellina modesta*).

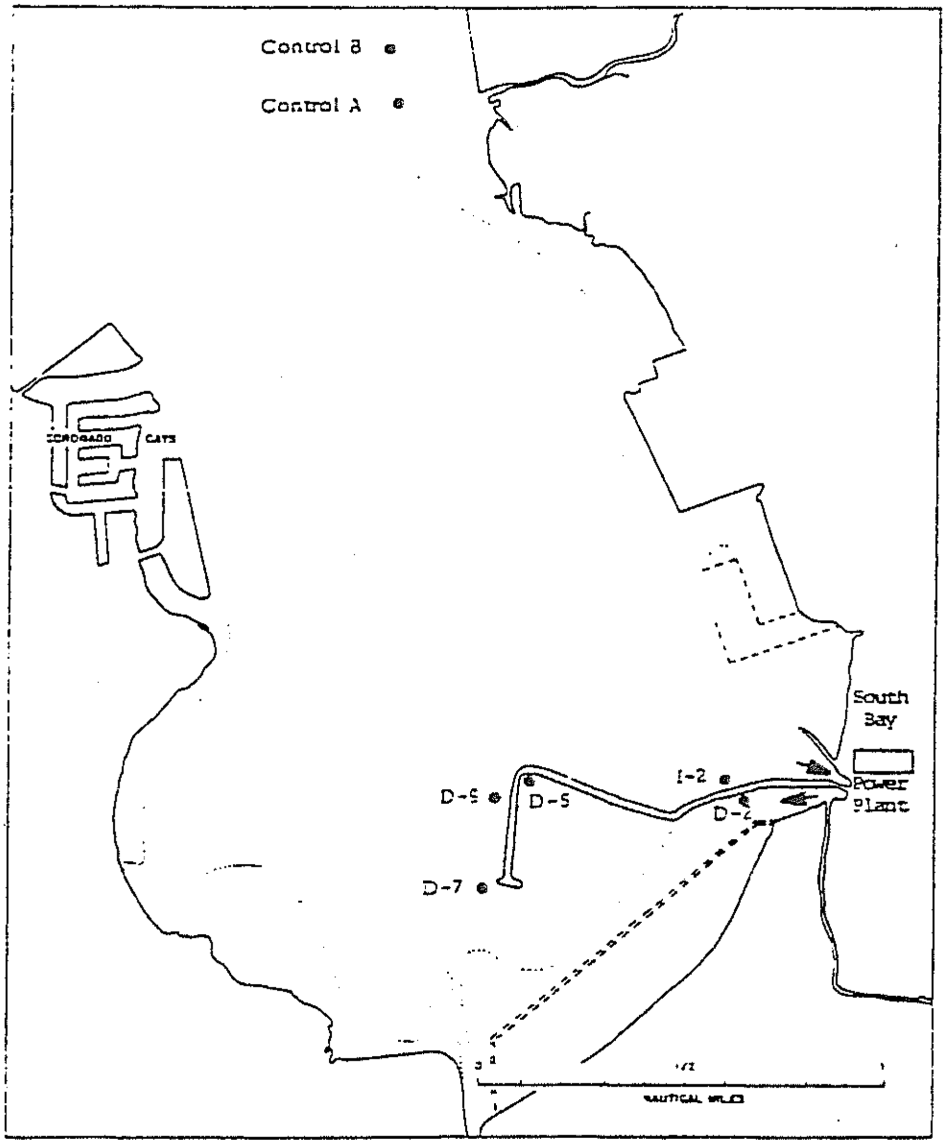

Figure 1. Sampling station locations for Control Stations A and B, and Test Stations D-9, D-7, D-5, D-2 and I-2, in San Diego Bay. →: indicates cooling water intake, and ←: indicates cooling water discharge for the South Bay Power Plant.

The test study area near the South Bay Power Plant was located along an L-shaped earthern dike, approximately 2300 m (1.30 miles) long, which extends west into the bay from the power plant (Figure 1). This dike, constructed by the San Diego Gas & Electric Company at the time the power plant was established, separates the cooling water chan- nel discharge of the plant from the bay, providing a large area for mixing and heat exchange before the thermal effluent is discharged to the main part of the bay.

The shoreline of the dike is a mixture of sand, rock, gravel, silts, clays, and shell debris in differing proportions along its length, both intertidally and subtidally. Generally, rocks, cobble, or gravel predominate above Mean Sea Level (MSL), while sands, silts, clays, and shell debris occur below that level. The silt/clay content of the sediment increases from high intertidal to subtidal elevations on the shoreline of the dike.

Portions of the north, west, and southern tip of the dike have developed into mudflats typical of those in the control area and elsewhere in Southern California bays and estuaries.

The inner portion of San Diego Bay is characterized by water depths averaging only 1 m below MLLW, except in dredged channels 2-4 m deep. The width of the bay in the study area varies from 1.6-2.8 kilometers. Tidal flushing is the primary factor responsible for circulation of the bay water. Ford and Chambers (1974) reported that water in the entire bay could be replaced in two days if tidal flushing were 100% efficient. However, since flushing is relatively inefficient in the inner bay, such water quality characteristics as surface temperatures and dissolved oxygen concentrations show greater short-term and seasonal variation than in the outer parts of the bay. During the year surface water temperatures range from 12°C - 23°C at the bay entrance in comparison to ranges of 14.5°C - 26°C for the inner bay. Poor flushing characteristics and high evaporation rates in the shallow inner bay also result in water salinities above 35°/oo during the late summer and early fall. Similarly, relatively low dissolved oxygen concentrations occur in and around the cooling water channel. These are associated with relatively high ambient and effluent water temperatures characteristic of summer and early fall conditions. The physical, chemical and biological characteristics of inner San Diego Bay have been studied fairly extensively within the last 20 years (Marine Advisors, 1958, 1961, 1963, 1968; Ford, 1968; Ford et al. 1970, 1971, 1972; Ford and Chambers, 1973, 1974; Chambers and Chambers, 1973; Peeling, 1975).

METHODS

Field studies to obtain the basic information required were conducted in San Diego Bay during the period August 1971 - December 1975. Data on population characteristics of S. rosaceus and T. californianus were obtained on a regular basis during all seasons of the year from September 1971 through December 1973. These included data on density, size-frequency distributions, rates of growth and mortality, reproductive condition, and distribution patterns of the two bivalve species.

Data were taken at a series of representative station locations within the thermal plume of the South Bay Power Plant (test area) and at a control location outside the influence of the thermal plume (control area) (Figure 1). Additional data on temperature and other physical factors were obtained from reports of environmental monitoring studies conducted for the San Diego Gas & Electric Company by Environmental Engineering Laboratory, Inc. during this same period (Chambers and Chambers, 1973; Ford and Chambers, 1974).

Because S. rosaceus and T. californianus are sedentary, their distribution and population characteristics within and outside the thermal plume should reflect in a fairly direct way their responses to temperature and other environmental conditions in the bay. Related laboratory experiments were conducted to determine upper lethal thermal tolerances under constant temperature conditions and under fluctuating temperature conditions simulating those which occur in the study area, then rays would account for an estmiated 2.1% loss for that period. However, one does not know how recently these feeding depressions were produced by the rays or how long they persist after feeding.

Menge and Sutherland (1976) presented a model for relatively predictable and benign environments in which predation was considered to be the main structuring agent. Van Dolah (1978) presented evidence to support that model for a saltmarsh community in which predation was a primary factor in observed seasonal changes of distribution and abundance in the dominant epifaunal amphipod, *Gammarus palustris*. He found that intra and interspecific competition were minimal.

Woodin (1976) has proposed that adult-larval interactions are an important factor in maintaining discrete boundaries between dense infaunal assemblages (i.e. deposit feeders, suspension feeders, and tube builders). She presented evidence to show that the main interaction between adult and larval suspension feeders was that of adults filtering spat from the water column, and ingesting new settled young which were resuspended by disturbance of sediment. Fitch (1965) suggested that the density of adult pismo clams (*Tivela stultorum*) in one study area was a factor in reducing successful recruitment by filtering all spat out of the water column.

The adult-larval competitive interactions postulated above could be important regulating factors for *S. rosaceus* and *T. californianus* populations. These populations should also be size-class dominated due to periodic recruitment failures once a dense population is established (Woodin, 1976; Fitch, 1965).

S. rosaceus was strongly size-class dominated at MLLW (control station A) from 1971 to 1974. However, at 0.5 m below MLLW, size classes were not as distinct over the four-year period (Figures 28 and 29). These figures suggest that when a larger size-class was dominant recruitment was suppressed. When a juvenile size-class was dominant the larger size-classes were not abundant.

Similar size-class dominance was also apparent for T. californianus (Figures 30 and 31). It was most evident at control station A and test stations D-7 and I-2. The dominance of a single size class at test station D-2 was influenced primarily by heated effluent from the South Bay Power Plant. This discussion supports the hypothesis that adult-larval interactions in relatively dense populations may be important factors in the regulation of S. rosaceus and T. californianus. The failure to detect density-dependent regulation by the rate of loss method (Horst, 1976) when comparing adult populations from control and test station locations may indicate the over-riding influence of elevated water temperatures on the bivalve molluscs used for comparisons, or the lack of sensitivity of this method to the circumstances presented.

Biological Effects of Thermal Effluent

Data from my study showed that heated effluent from the South Bay Power Plant affected the distribution, abundance, growth, and reproductive characteristics of both S. rosaceus and T. californianus.

Thermal tolerance and resistance data from the laboratory studies revealed that *T. californianus* was better able to withstand higher water temperatures than *S. rosaceus*. This evidence shows that the effective time to 50 percent mortality in *T. californianus* at 31.5°C was 144 hours for individuals ranging in size from 25 - 55 mm. On the other hand, *S. rosaceus* had an effective time of only 7 hours to 50 percent mortality at 31°C. Field data also showed that while *T. californianus* could live within 750 m of the point of discharge for thermal effluent at station D-2 (Figure 1), *S. rosaceus* was restricted to areas near station D-7 and beyond, a distance of more than 2100 m from the point of discharge. Mean "effective time" is used in the following discussion to consider the distribution of the two species in and around the cooling water channel.

Surface water temperatures at test station D-7 exceeded 28°C continuously over several 24 hour periods in July 1972 (Kellogg, 1975). From late July through mid-September 1972 - 1973, surface water temperatures at station D-7 below 28°C were uncommon. At 28°C my laboratory results on thermal resistance would predict 50 percent mortality among *S. rosaceus* after 48 hours. That a *S. rosaceus* population existed at all during the July-September period at station D-7 suggests it has some mechanism to modify the potentially lethal effect of such high water temperatures. The effect of temperature was significant, however, since densities of *S. rosaceus* at the control station from July-September were 2-10 times those at station D-7.

A probable mechanism that allows S. rosaceus to survive in the intertidal zone at station D-7 is the temperature buffering capacity of the sediments. Figure 36 shows the temperature buffering capacity of the sediments at 2 cm and 20 cm depths. On 3 July, 1972, when subsurface water temperatures were in excess of 28°C, sediment temperatures at 2 cm and 20 cm were 22.2°C and 26.7°C respectively. It is likely, therefore, that potentially lethal water temperatures impinged upon the test population only during that period when the mudflat was covered with water. This modifying effect was also suggested from the results of my temperature cycling experiments. When exposed to a cyclic temperature change of 20° - 30°C, 50 percent mortality of S. rosaceus occurred between 60 and 72 hours.

Another factor that may be involved is acclimation to high water temperatures. Solen rosaceus acclimated to 25°C had an LT_{50} of 30°C, in contrast to an LT_{50} of 29.5°C for individuals acclimated to 20°C. Waugh (1971) presented evidence that upper lethal tempera- tures in Modiolus demissus declined in relation to declining mean monthly substrate temperature. The reverse is not always true, as was the case with the scallop, Placopecten magellanicus (Dickie, 1958). Ambient temperature, however, may reflect the current acclimation state of the species (Waugh, 1971). This suggests that the higher the ambient temperature, the higher the temperature a species can with- stand, up to a point. For S. rosaceus living at a temperature level close to 30°C, the LT_{50} temperature may be increased by 0.5°C to 30.5°C, thus affording slight

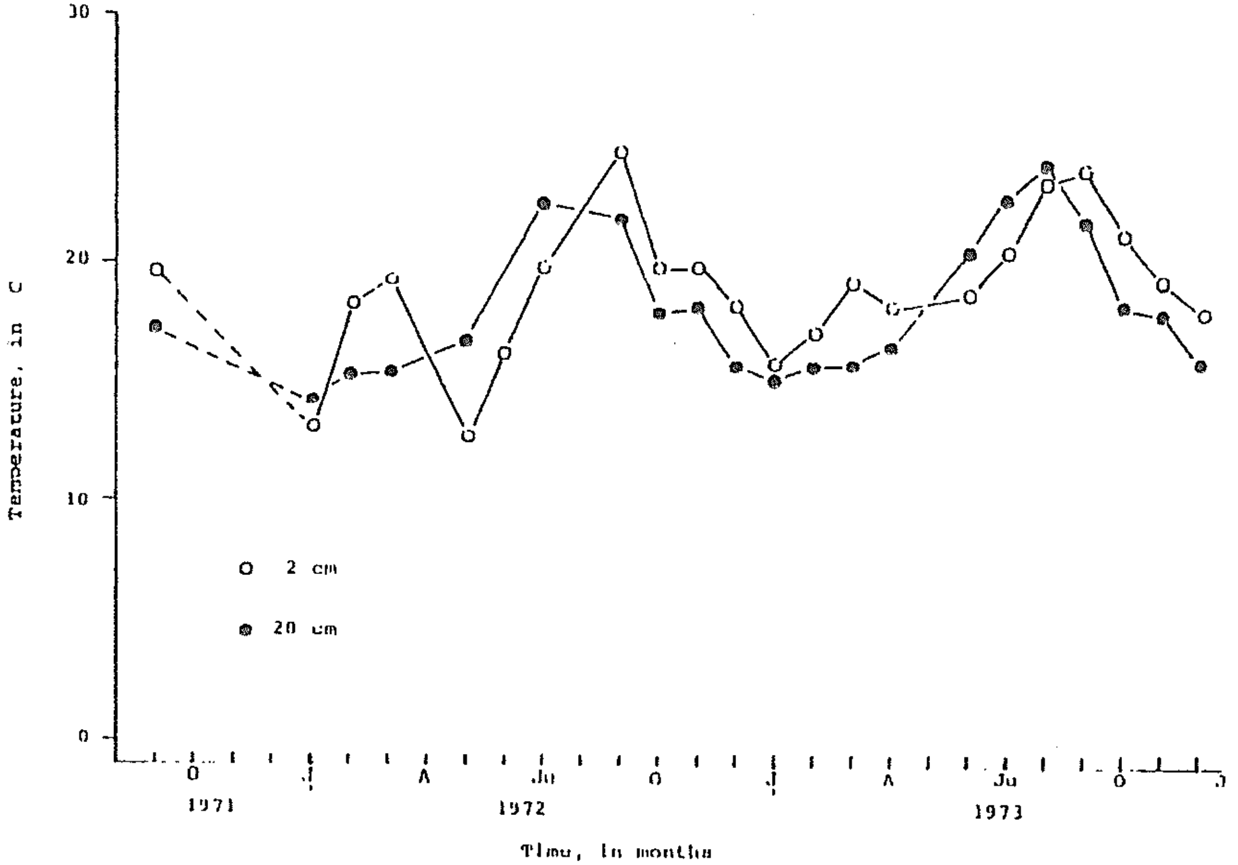

Figure 36. Sediment temperatures at control station A, MLLW, taken at monthly intervals with a bimetallic stem thermometer to show the seasonal temperature buffering action of the sediments in the mudflats. ●:sediment temperature at 20 cm depths; O:sediment temperature at 2 cm depths.

additional resistance to high water temperatures.

These arguments are applicable to *T. californianus* at station D-7. At 31.5^{o}C mean effective time to 50 percent mortality for *T. cali- fornianus* is 144 hours. During July 1972, 1973, this temperature was exceeded 40 percent of the time at the location of the subsurface temp- erature recorder. However, given the nature of tidal exposure at this station, the temperatuire buffering capacity of the sediments, and the relatively long mean effective time of *T. californianus*, one would ex- pect little effect on individuals living there. This is supported by statistical analyses which suggested no significant differences between densities and mortality rates of *T. californianus* at station D-7 and control station A.

In August 1972 - 1973, water temperatures in excess of 33^{o}C occurred almost continuously at test station D-2 . During this month in both 1972 and 1973, gaping and moribund *T. californianus* (42 mm - 50 mm in length) were observed in the upper part of the sediment. By September no large individuals were found alive at station D-2. Mean effective times to 50 percent mortality for all size groups of *T. cali- fornianus* were quite short for temperatures existing at station D-2 in August (Table 15). Sediment temperatures during this period were also above 32^{o}C, which indicated that the buffering capacity of the sedi- ment was insufficient to lower temperatures below the lethal level.

Predicted resistance time values suggest that for densities of *T. californianus* of 1.5 - 2.5 per 1140 cm^2 and with water and sediment temperatures above 31.5°C, all large T. californianus would die within three weeks. Evidence from the temperature cycling experiments with a range of 25°C - 35°C supports this conclusion, since approximately 37 percent mortality occurred after 72 hours. Furthermore, densities of T. californianus from the control and outer test stations were significantly greater than those at station D-2, which suggests an adverse impact from elevated water temperatures at this inner station.

Within the size ranges tested (27 - 57 mm), there was no indication that S. rosaceus had a size specific response to lethal temperatures. The most obvious size specific mortality in T. californianus was observed for those individuals greater than 55 mm in length (see Table 15) where resistance to a 50 percent mortality was 4.4 hours compared to 41.5 hours at the same temperature for individuals $<$ 52 mm in size. Small juveniles and recently settled spat were probably least affected by sediment and water temperatures during September at MLLW, since by early October in both 1971 and 1973 T. californianus up to 13 mm in size were collected at this station.

Kennedy and Mihursky (1971) reported that young Mya arenaria and Macoma balthica were more tolerant of high water temperatures than were older, larger individuals of the same species. In contrast, Wallis (1975) found that medium-size Mytilus edulis (3 cm - 5 cm) would die more quickly at a given lethal temperature than individuals greater than 5 cm in length. No influence of size on thermal resistance was reported for the tropical mussel Trichomya hirsuta

(Wallis, 1976), or for the ribbed mussel, Modiolus demissus (Waugh & Garside, 1971).

Growth rate, longevity and maximum size of bivalve molluscs are strongly influenced by temperature (Kinne, 1963). Gilbert (1973) presented evidence to suggest that growth rate and maximum size in Macoma balthica decreases and longevity increases with increasing latitude, cooler temperatures, and shorter growing season. Intertidal populations of Mytilus edulis at an Alaskan location had lower growth rates than California populations (Dehnel, 1956). At higher temperatures M. balthica grew faster but had a shorter life span (Green, 1973; Gilbert, 1973).

Mean growth rates in terms of shell length, described by K, the Brody-Bertalanffy growth coefficent, were enhanced in both S. rosaceus and T. californianus as water temperatures increased. The most rapid growth was observed in those T. californianus populations nearest the effluent outfall (station D-2). The growth coefficient, K, for S. rosaceus at station D-7 was twice the value of K observed at the control stations, indicating much more rapid growth due to higher water temperatures. The growth coefficent for T. californianus at station D-2 was 5 times the value of control station A (Table 11). Wolfson (1974) reported that high temperatures increased growth of two bi- valves, Mytilus edulis and Hiatella artica, after they settled in experimentally heated tanks, while Bunting (1971) observed decreased growth in Mytilus edulis at localities close to the point where thermal effluent was discharged from a power plant in San Francisco

Bay.

While the above studies have described differences in growth rates, maximum size, and longevity with respect to latitudinal differences, I found that both S. rosaceus and T. californianus had a smaller maximum size, shorter life span, and greater growth rate due to increased temperature of thermal effluent from the South Bay Power Plant (Figures 24 and 25) than did individuals occurring at ambient temperatures of control stations a short distance away . For example, the largest T. californianus collected at control station A (82 mm in shell length) was estimated to be at least 4 years old, with a growth coefficent value of 0.405. In contrast, no T. californianus lived over one year at test station D-2. The largest individual taken at station D-2 was 46 mm in shell length. The growth coefficent was 2.315 at that location.

Newell (1969) suggested that compensatory metabolic changes occur in intertidal animals in response to different temperature conditions, with an increase in activity at low temperatures and suppression of activity at high temperatures. He further suggested that in a quiescent animal, respiration rate is independent of temperature over the normal range in the environment.

Regarding the smaller maximum size of S. rosaceus and T. californianus exposed to heated effluent, one can conclude that these species at some point must be expending more energy for respiration, and possibly for reproduction, than for growth (see, for example, Gilbert, 1973). Perhaps energy requirements for rapid growth and reproduction are met up to a certain size of animal and given water temperature near the cooling water channel (Ansell, 1969). Beyond that size and water temperature limit, all energy must be channeled into maintenance, causing a cessation of growth. This effect may be due to poorer nutrient conditions or lower oxygen tensions, coupled with a higher surface to volume ratio in larger individuals that increases oxygen demand. It could result in thinner shells, reduced volume and weight of soft tissue, and eventually death (Kellogg, 1975).

The effect of temperature on reproduction was considered on the basis of evidence concerning the relationship of change in body weight with time for adult animals. Over the spawning season, individuals of S. rosaceus and T. californianus, which lived at test station D-7, exhibited a larger increase in body weight. This increase was maintained over a longer period than for S. rosaceus and T. californianus at control station A. Secondly, the decrease in body weight, suggesting spawning, was less in individuals from test station D-7. These two observations suggest a longer spawning period in S. rosaceus and T. californianus from test station D-7. This indirect evidence is, of course, hampered by the lack of gonadal indices to indicate reproductive activity more directly. However, the available evidence is particularly significant when one considers that both S. rosaceus and T. californianus from the test area reached a smaller maximum size than did individuals from the control stations had an overall greater increase in body weight.

Gamete production may take place in late winter and early spring in some bivalve molluscs. Spawning usually occurs when some critical temperature is reached (Loosanoff & Nomejko, 1951). Should spawning of *S. rosaceus* and *T. californianus* occur earlier due to higher temperatures at the cooling channel locations, one might expect that planktonic larval stages would be carried to the control area and settle there. These newly settled juveniles should have been present in monthly bottom samples, but were not. However, *S. rosaceus* as small as 1.4 mm in size were present in January samples from the outer test stations.

Wolfson (1974) suggested that early spawning may introduce larvae into the water column when they are least prepared to survive due to excessive temperatures, poor food conditions, and the presence of efficient predators. In contrast, Loosanoff and Davis (963) reported that bivalve larvae can survive sharp temperature changes. Efficient grazing by predators and poor food conditions in the water column should not normally be a problem since juvenile density data suggested that young bivalves were present through many months of the year.

CONCLUSIONS

The evidence presented in this study indicates that elevated water temperatures in the vicinity of the South Bay Power Plant are important in determining the large-scale distribution patterns and population characteristics of *S. rosaceus* and *T. californianus*. While the temperature buffering ability of the sediments offers some protection from upper lethal water temperatures, *S. rosaceus* appears to be restricted in distribution to areas where sediment temperatures rarely exceed 28°C. On the other hand, *T. californianus* are found where sediment temperatures approach 34°C.

Although densities of *S. rosaceus* at the outer test stations are significantly less than densities of *S. rosaceus* at the control station, individuals grow faster but reach a smaller maximum size. Similarly, densities of *T. californianus* within the cooling water channel are affected by the heated effluent and are less than densities of *T. californianus* at the control and outer test stations. The growth of *T. californianus* within the cooling water channel is also faster than growth of *T. californianus* beyond the channel, and a smaller maximum size is attained. What is observed here at South San Diego Bay within a distance of 5 killemeters is reported in the literature for distances of hundreds of miles in latitude.

Reproduction of *S. rosaceus* and *T. californianus* may be enhanced in the vicinity of the South Bay Power Plant. The weight gain of individuals of both species suggests that spawning may be extended into the late summer months. Indirect evidence for this extension of the spawning period is also supported by juvenile *S. rosaceus* as small as 1.4 mm in length being present in grab samples during winter months, and the presence of juvenile *T. californianus* in samples throughout much of the year.

Annual mortality rates of *S. rosaceus* were significantly higher at the test stations than at the control station, presumably due to higher water temperatures at test stations D-7. The annual mortality rate of *T. californianus* was highest at test station D-2, the point nearest the discharge of thermal effluent. At this location *T. californianus* became an annual species: recruitment into that population occurred in later summer/early fall, and the cohort died during the next summer.

An analysis of size-frequency distribution histograms suggests that *S. rosaceus* populations are characterized by one and possibly two recruitment waves per year. The apparent second wave is likely an extension of the spawning season near the cooling water channel. A similar analysis for *T. californianus* indicates these populations are characterized by constant recruitment, exponentially decaying growth, and increasing mortality.

The predominant random small-scale dispersion pattern of *S. rosaceus* and *T. californianus* in a fairly homogeneous environment, and the strongly size-class dominant populations suggests insignificant adult-adult and significant adult-larval interactions, a possible regulating factor in their populations. Regulation may occur by adults filtering spat and recently settled juveniles from the water column or resuspended sediments and causing recruitment failures.

Thermal tolerance and resistance studies indicate that T. californianus can withstand higher water temperatures than S. rosaceus. The data on resistance or "effective time" predicts that S. rosaceus should not occur much closer to the point of thermal discharge than test station D-7 and D-5. This was verified through the field study. On the other hand, the higher resistance to thermal effluent by T. californianus allowed this species to occur well within the South Bay Power Plant cooling channel.

Life history traits differ between control and test station locations because of the influence of elevated water temperatures of the latter. Individuals from test station locations are characterized by more variable reproductive effort, fewer young, (as determined by juvenile densities) and shorter life span, while individuals from the control station locations are characterized by a more predictable breeding cycle resulting in numerous young. A longer life span, and larger size and presumably iteroparity, is also characteristic of the populations unaffected by the increased temperatures due to coolant discharge.