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CHARTOPS: SIMULATING SHORT-TERM USE OF THE TUNA PRUSE-SEINE FLEET TO SURVEY DOLPHIN SCHOOLS IN THE EASTERN TROPICAL PACIFIC OCEAN

Elizabeth F. Edwards
Pierre Kleiber

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center

NOAA Technical Memorandum NMFS

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ABSTRACT

Simulation model results indicate that short-term charters of the eastern tropical Pacific tuna purse-seine fleet to survey dolphin schools can be a very ineffective procedure for deriving estimates of dolphin school abundance. Simulations were conducted in which fishing operations were stopped simultaneously for the entire fleet and replaced by survey procedures for the subsequent 24-hr period. School abundance estimates were generally variable and positively biased (high), while during the second 12-hour period, the estimates of school abundance were generally negatively biased (low) but still variable. The positive bias during the initial 12-hour period resulted from the concentration of tuna vessels in areas of high density at the start of the "survey period". The negative bias in estimates from the second 12-hour period resulted from an interaction between the spacing of tuna vessels relative to areas of dolphin abundance, speed of tuna vessels, and size of dolphin school patches, such that during this period tuna vessels tended to have left the original concentrations of dolphins but not yet entered a new concentration.

More complicated chartering schemes might be more effective, but in any case, the effectiveness of any scheme will be affected strongly by the (unknown) true spatial and temporal distribution of dolphin schools. The fundamental problem with any scheme will be the initially non-random (but unquantified) distribution of tuna vessels with respect to the non-random distribution of dolphin schools.

INTRODUCTION

The U.S. National Marine Fisheries Service (NMFS) is responsible for managing mortality of dolphins affected by the U.S. purse-seine fishery for tuna in the eastern tropical Pacific Ocean. This requires estimates of trends in dolphin abundance. Dolphin abundance is currently estimated based on sightings data collected during research surveys conducted by NMFS. An alternative data source is the tuna fleet itself, as the vessels spend considerable time at sea searching for and interacting with schools of dolphins.

However, the nature of this interaction is problematic with respect to estimating dolphin abundance. Tuna vessels actively search for dolphin schools, and thus spend a disproportionate amount of time in areas where dolphins are most common, avoiding and therefore undersampling those areas where dolphins are relatively scarce. The underlying problem is that the active search for dolphins by tuna vessels produces non-random distributions of tuna vessels relative to spatial distributions of dolphin schools. This is a problem because a fundamental tenet of line transect analysis - the analytical method most appropriate for estimating dolphin school abundance - states that sighting platforms must be distributed randomly with respect to the sighted objects.

One potential solution to this problem of nonrandom search producing nonrandom distributions of boats, and thus nonrandom data, is to have the fleet cease fishing at a given time, to then assign each vessel in the fleet a random direction of travel, and then to ask observers on each vessel to collect sightings data as the vessels travel along their assigned tracks for some specified period of time. The hope is that data collected during this charter period will be less biased than data collected during fishing, when tuna vessels tend to concentrate on areas of high dolphin density and avoid areas of low density. Testing this solution with the real fleet would be an expensive and complicated proposition. Simulation modeling offers a more efficient and less expensive approach.

We describe here the effects on estimates of dolphin school abundance, of simulating charters of the entire purse-seine fleet simultaneously for 24 hours.

METHODS

Model characteristics. We used TOPS (Tuna-vessel Observer Program Simulator; Kleiber and Edwards 1988) as the simulation environment for the charter experiment. TOPS simulates the movements of dolphin schools and tuna vessels in a non-random environment of area 1200 x 1200 nautical miles squared (1,440,000 n. $mi.^2$). Dolphin school speed and direction are controlled by school

reactions to an underlying "environmental topography", producing non-random spatial distributions of dolphin schools as the schools congregate in areas of favorable habitat and avoid areas of unfavorable habitat. Direction and speed of tuna vessels are controlled by the sighting history of individual vessels. Vessels slow down and turn more frequently in areas where dolphin sightings have been frequent, thus vessels congregate in the vicinity of dolphin schools. Vessels speed up and tend to turn less frequently when school sightings have been rare, thus vessels spend disproportionately less time in areas with few dolphin schools.

The major difference between this charter version and earlier versions of TOPS is that the charter version simulates the movements of only 30 vessels, rather than the 75 included earlier. Number of dolphin schools is unchanged from earlier versions, remaining at 2500 schools. School size is assumed to be constant in these simulations, and therefore does not contribute to variations in dolphin abundance among runs. Fewer vessels are used here to simulate only the U.S. portion of the total international fleet, as only U.S. vessels can be required directly by NMFS to carry observers and participate in a charter exercise.

Simulation conditions. A secondary difference between the charter and earlier versions of TOPS is that the charter version includes two additional environmental topographies (Figures 2 and 3) intermediate to those used in earlier simulations (Figures 1 and 4). We tested the effects of chartering the fleet under a total of 5 configurations of environmental topography, where in all cases the topographies were static throughout the simulation. We did not include dynamic environments in this set of simulations because the charter period lasted for only 24 hours, and vessels move at about 15 knots compared to average movements of oceanic features of about 1 knot. The environment moves so much more slowly than the vessels, and the charter period is so short, that effects of dynamic environments would go unnoticed.

Environments tested included 1 totally random environment, which generated totally random distributions of dolphin schools, plus 4 environments with different combinations of peak slope and peak number. Peak slopes were gentle or steep, peak number was 4 or 16, ranging from a simple gentle topography with 4 gently sloping peaks (Figure 1) to a complex steep topography with 16 steeply sloping peaks (Figure 4).

Within each simulation, 30 fishing vessels are introduced at random positions at time zero. Prior to the charter period, these vessels spend 600 hours conducting normal fishing activities, searching for schools and stopping for five hours whenever a school is encountered. At the beginning of the charter period, each vessel is assigned a random direction. Starting from this current position, the vessels travel steadily at 15 knots in the selected direction for 24 hours, counting the number of dolphin schools

observed within 2 n mi. of either side of each vessel. In contrast to the fishing period, during the charter period boat speed is not affected by sightings of dolphin schools. Each set of simulation conditions was replicated 6 times.

"Data" collected. During the entire simulation, records (counts) were kept of all schools appearing within 2 nm on either side or ahead of each vessel. Lists of sighted schools were kept to avoid re-counting schools from one time step to the next. This device is necessary in the simulation model to prevent the vessels from "forgetting" that they have seen a nearby school the previous hour (time-step). Estimates of dolphin school abundance were derived from these data each hour for the first 600 hours, and then for 2 intervals within the 24-hour charter period; the initial 12 hours and the final 12 hours of the 24-hour charter period.

Estimates derived. Abundance estimates based on numbers of schools sighted and track miles accumulated by all thirty vessels were calculated for each 10 hours of the normal fishing period and for the first and second 12 hours of the charter period, within each replicate simulation. Estimates of dolphin school abundance during any time period were derived from vessel sightings as the total number of schools observed by all vessels during a given period of time (hourly for the first 600 hours of simulation, every 12 hours during the charter period), multiplied by $1.44*10^6/(4*T_m)$ where T_m is the total nautical miles (n. mi.) of trackline searched by all vessels during the period, $1.44*10^6$ is the total area simulated (n. mi. squared), and 4 (n.mi.) is the effective strip width of the searched tracks.

RESULTS AND DISCUSSION

Results are not encouraging for this particular design of fleet charter. Estimates are too high in the beginning of the charter period, when vessels are still inside patches of dolphin schools. Estimates are too low later in the charter period, when vessels have left and not yet re-entered other patches. Estimates from beginning and ending periods cannot simply be averaged, as the early and late estimates are not equally spaced above and below the true abundance of dolphin schools. Specific results are reported below.

Random environment. Simulations with the random environment showed that the model was behaving properly (Figure 6). All 4 replicates varied more or less evenly about the actual dolphin abundance in the model (2500 schools) throughout the simulation period. As expected, the estimates, though scattered, tended to agree with that number, both during the fishing period and during the charter period.

Nonrandom environments. With dolphins aggregated, the results were very different (Figures 7-10). When fishing vessels were introduced at random positions, they first tended to underestimate true abundance of dolphin schools (for the first 10 to 100 hours, depending on environmental conditions) but as the vessels aggregated on patches of high density during the normal fishing period, the estimates exceeded the true value. The results from the charter period were highly variable, depending on the details of the charter arrangement and on the number and tightness of dolphin aggregations. In all cases tested, the data collected during the first 12 hours of the charter period greatly over-estimated dolphin school abundance, while data collected during the second 12 hours under-estimated abundance.

School abundance estimates (non-random environments). Each set of replicate school abundance estimates passed through four stages during each set of nonrandom simulations (Figures 7-10); 1) an initial period of fishing during which school abundance was underestimated, 2) the remainder of the fishing period, when school abundance estimates reached and exceeded true abundance, 3) the initial 12 hours of the charter period, when school abundance continued to be overestimated, and 4) the final 12 hours of the charter period, when school abundance estimates decreased and generally tended to underestimate true school abundance.

Understanding the reason for this pattern contributes much to understanding the effects of nonrandom spatial distributions of dolphin schools on estimates of school abundance. During the first period, school abundance was underestimated because the fishing vessels are not sampling both high and low density areas of dolphin schools in proportion to the respective areas. The boats, scattered randomly within the simulation area as the simulation

begins, over-sampled the low-density areas during this period.

Also during this first period, in areas of high density vessels traversed relatively fewer trackmiles because they were stopping so often to process schools. Thus for a given period of time, the vessels saw fewer schools in the high density areas than they would have if they hadn't had to stop for processing. This processing time effect will be relatively unimportant in the low density areas, simply because the boats will encounter so few schools there.

As the simulation progressed into the second period, school abundance estimates rose because the vessels became progressively more concentrated in the high density areas, to the exclusion of the low density areas. In this situation, there was a positive bias because of the high proportion of boats located in high density areas. This high density overwhelmed the negative bias caused by processing time.

The increase in this positive bias that occurred during the third period (the initial 12-hour period of the "charter"), again reflects the interaction between number of boats and number of trackmiles accumulated per boat. During the charter (periods 3 and 4) the boats stopped processing schools. Thus the boats traversed more trackmiles and counted more schools than they did during the preceding period. As the boats tended to be in high density areas at the beginning of the charter period (Figure 5), the positive bias increased during period 3 relative to period 2.

The decrease in bias, usually to an underestimate of school abundance, during period 4 (the second 12 hours of the charter) occurred because most of the vessels left the patches of high density but did not re-enter other patches before the end of the period. Thus most of the trackmiles accrued during this period occurred in regions of low dolphin density.

Although the qualitative characteristics of school abundance estimates derived during charters of tuna vessels are easy to understand (i.e., boats probably will start in high density areas and overestimate at first, then enter areas of lower density and begin to underestimate), quantifying those characteristics is not possible. The periods of over and underestimation depend on the speed of the vessels relative to the spatial extent and spacing of the patches, which are unknown.

Potential efficacy of alternative charter schemes and analyses. Although the charter scheme discussed here does not seem to be particularly effective, other schemes and other uses of the sightings data hold more promise.

One alternative use of sightings data from chartered tuna vessels is mapping the spatial characteristics of dolphin

aggregations. Assuming each tuna vessel begins in or near a clump of dolphins schools, sightings made along each track indicate one ray or traverse of the clump. Mapping the sightings provides an (albeit crude) approximation of the spatial distributions extant at the time of the charter (e.g., Figure 11). However, whether the original configuration of schools can be derived from these sets of sightings data will depend on undeterminable factors, such as the geometric uniformity of the clumps.

An alternative sampling scheme (Cormany[1]) would be to select random cruise tracks within the fishing area, then request fishing vessels which have ceased fishing for some reason, to survey along the nearest pre-determined trackline. In theory, this would supply a more truly random set of sighting transects. However, it is unlikely that all transects would be equally sampled. Transects near good fishing areas, or along common routes to and from ports and canneries, would tend to be over-sampled.

CONCLUSIONS

The 24-hour charter survey following normal fishing operations does not seem to be an effective method for collecting useful estimates of dolphin school abundance or trend data. However, such data might be useful for mapping dolphin school spatial distributions. Surveying pre-determined cruise tracks opportunistically might provide better estimates, but the method would probably require some sort of stratification.

ACKNOWLEDGEMENTS

The charter concept was suggested during a workshop convened at the Southwest Fisheries Center, La Jolla, CA, during February 1990, to evaluate the marine mammal research programs conducted by the Southwest Fisheries Service.

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[1]Cormany, D. 1990. Inter-American Tropical Tuna Commission, c/o Scripps Inst. Oceanog., La Jolla, CA 92039. pers. comm.

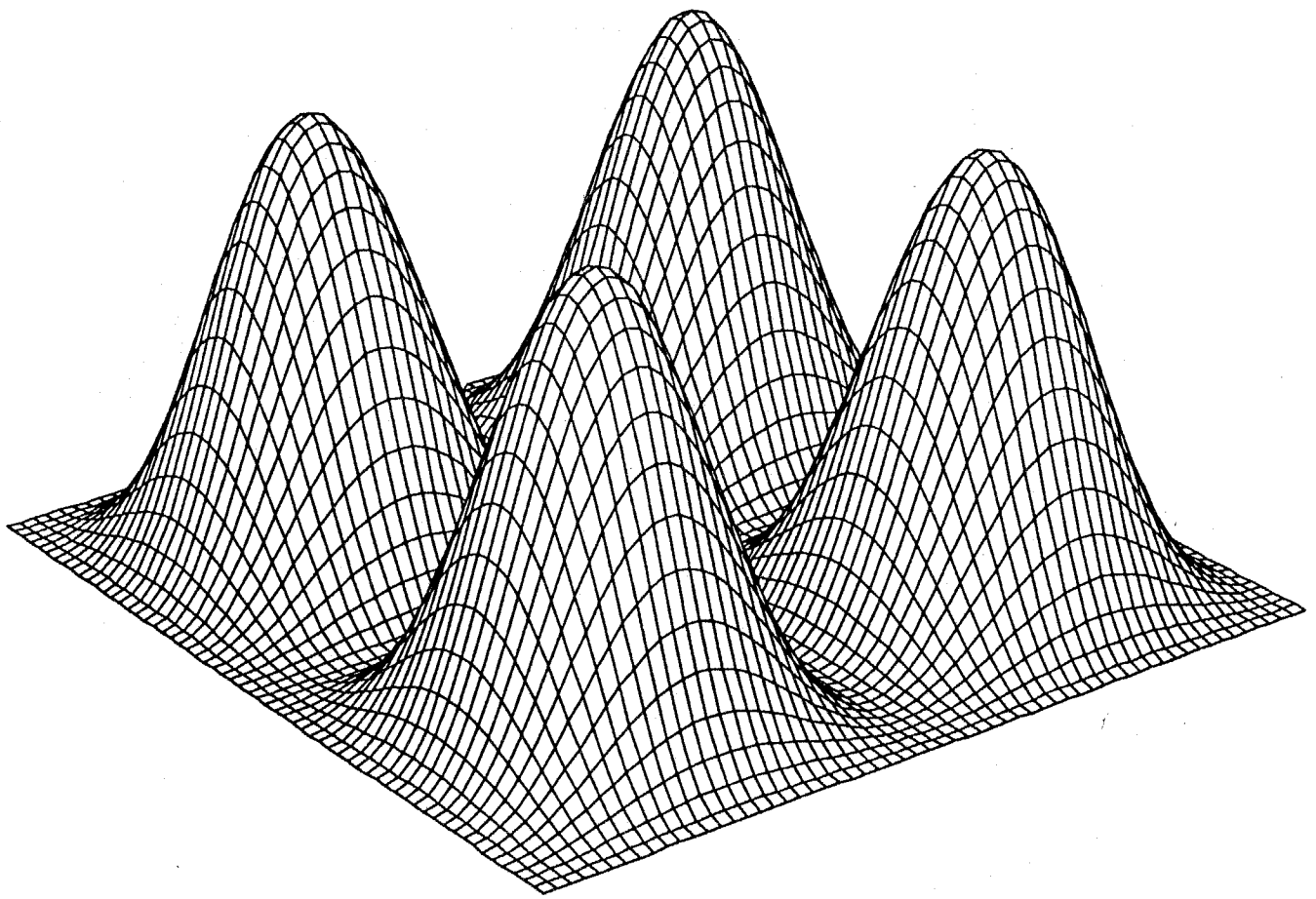


Figure 1. Environmental topography for case with 4 gentle peaks in the environmental gradient.

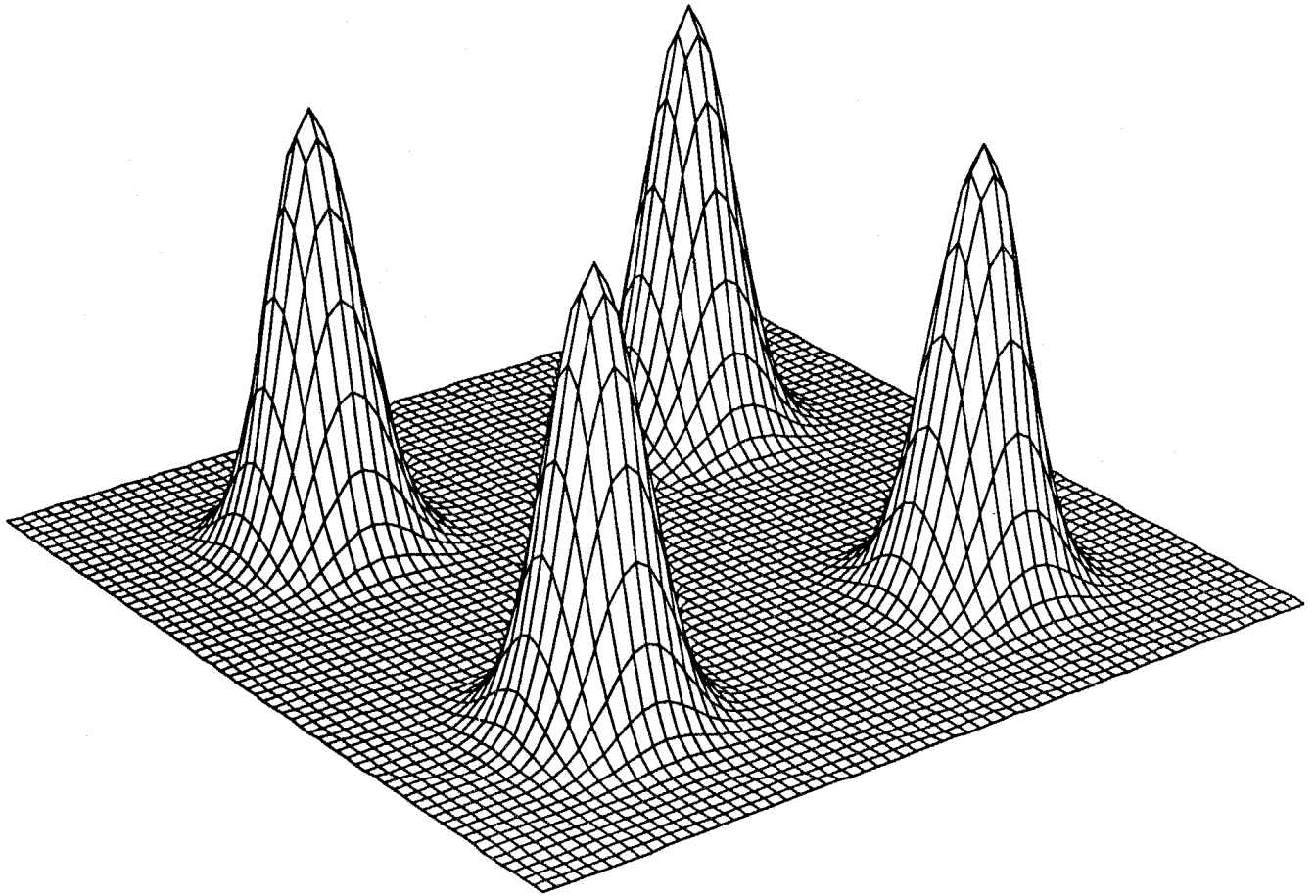


Figure 2. Environmental topography for case with 4 steep peaks in the environmental gradient.

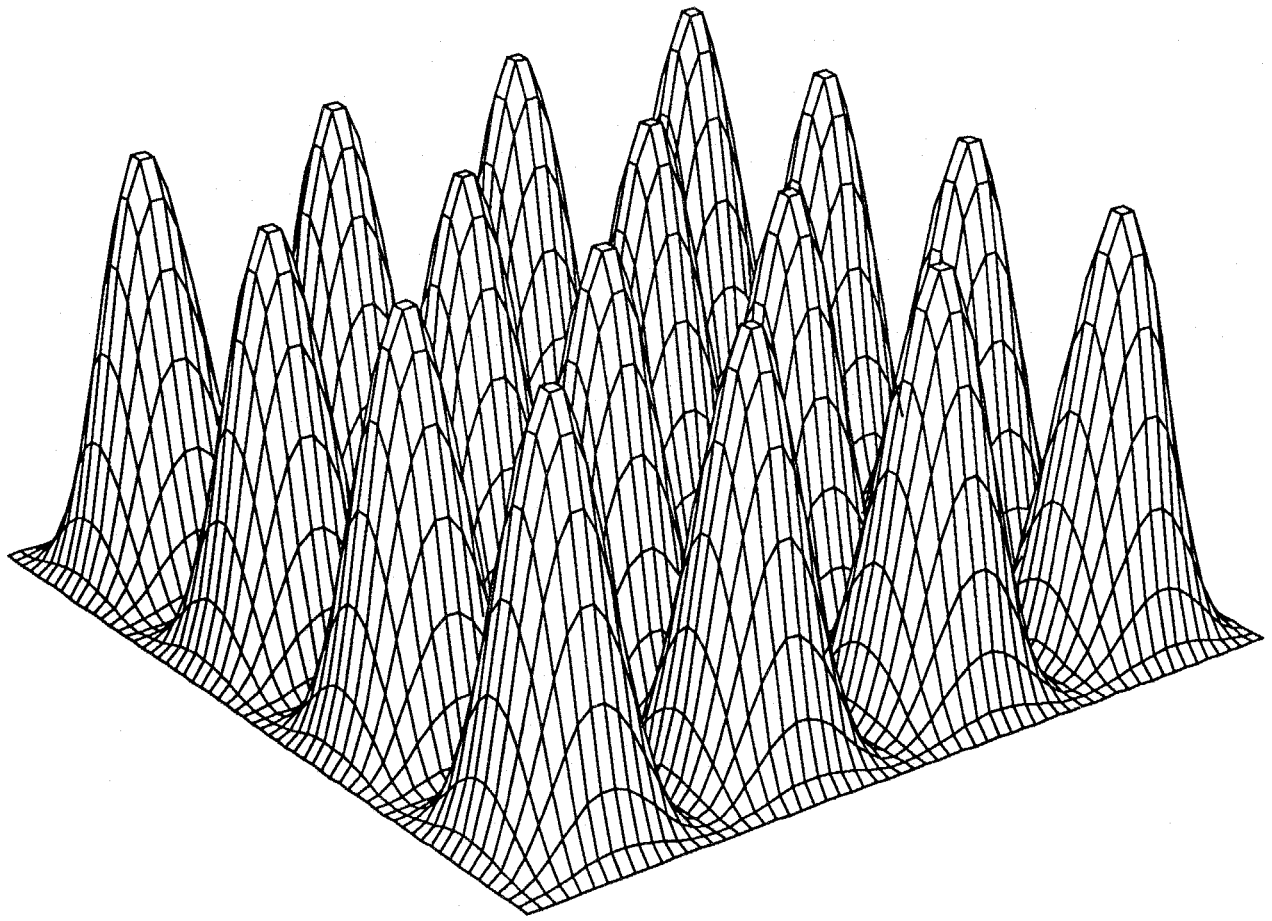


Figure 3. Environmental topography for case with 16 gentle peaks in the environmental gradient.

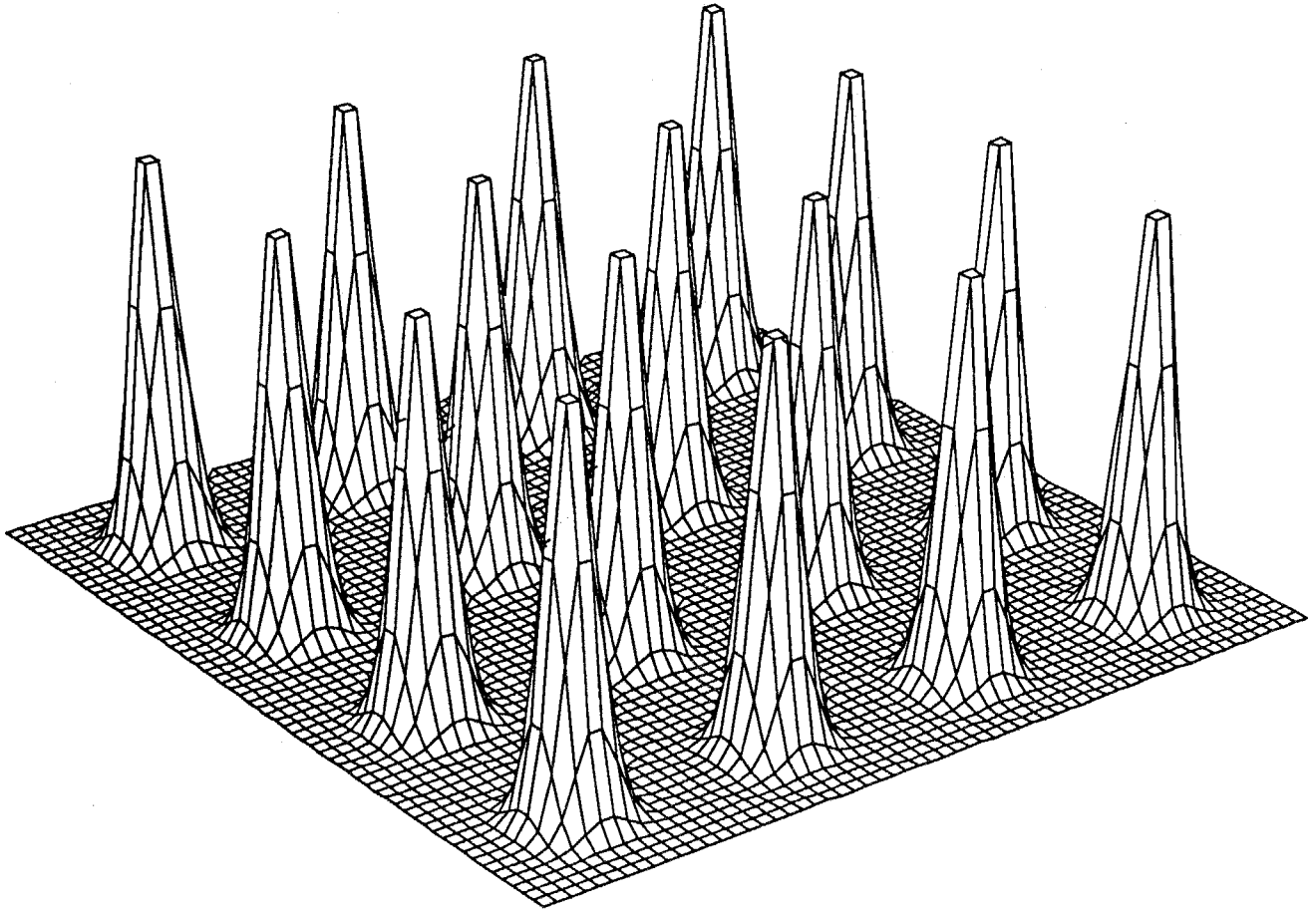
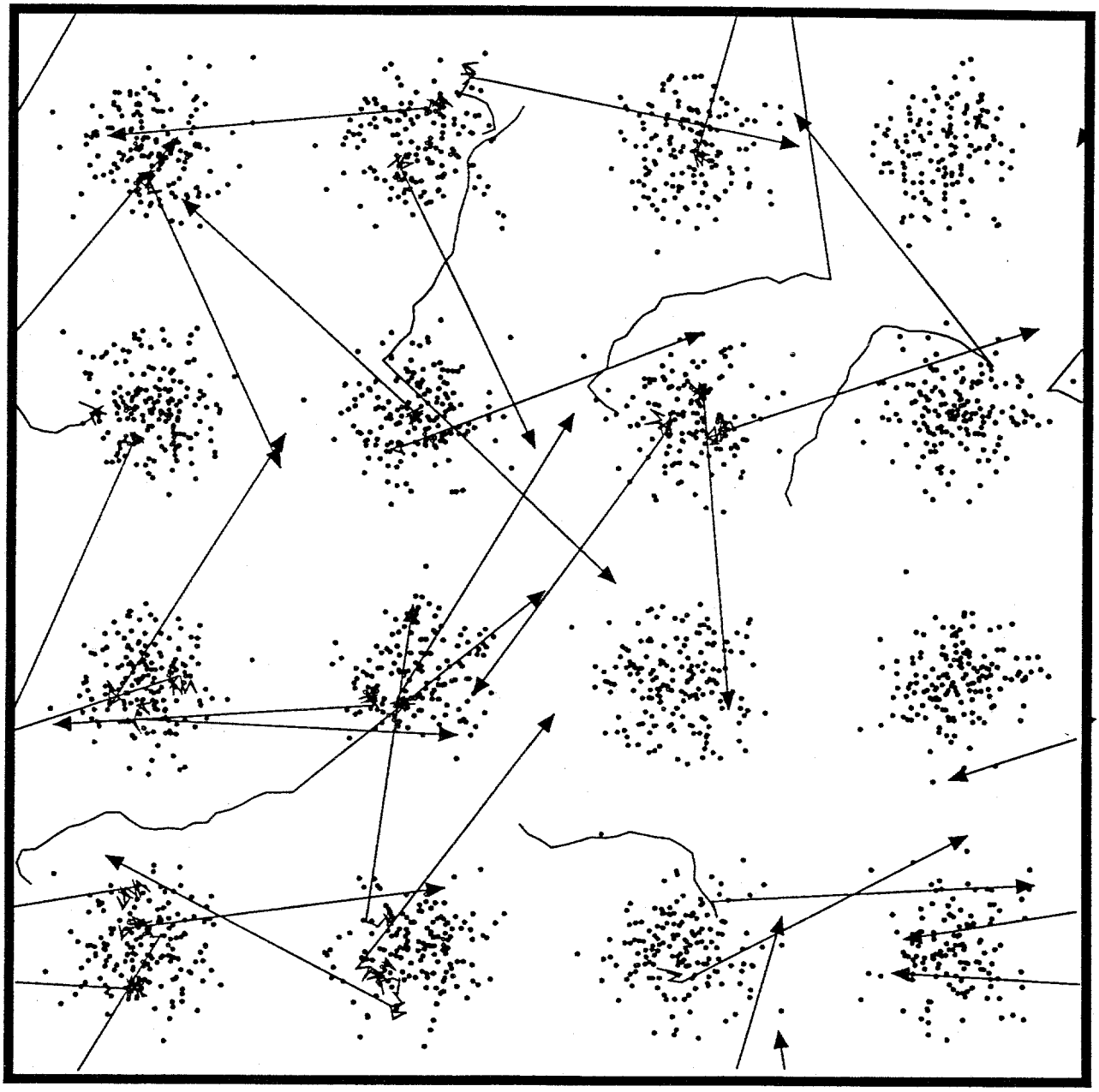


Figure 4. Environmental topography for case with 16 steep peaks in the environmental gradient.



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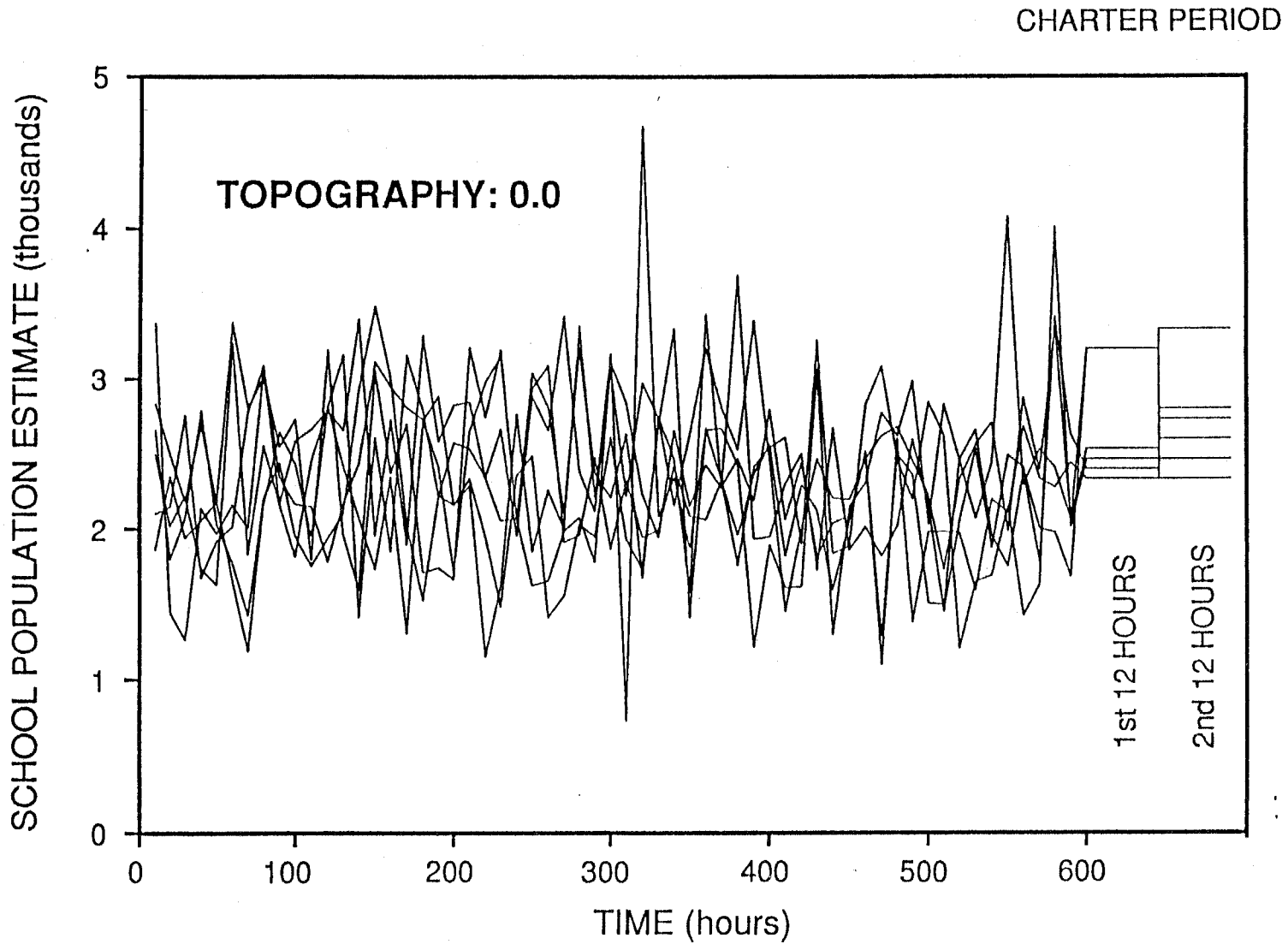

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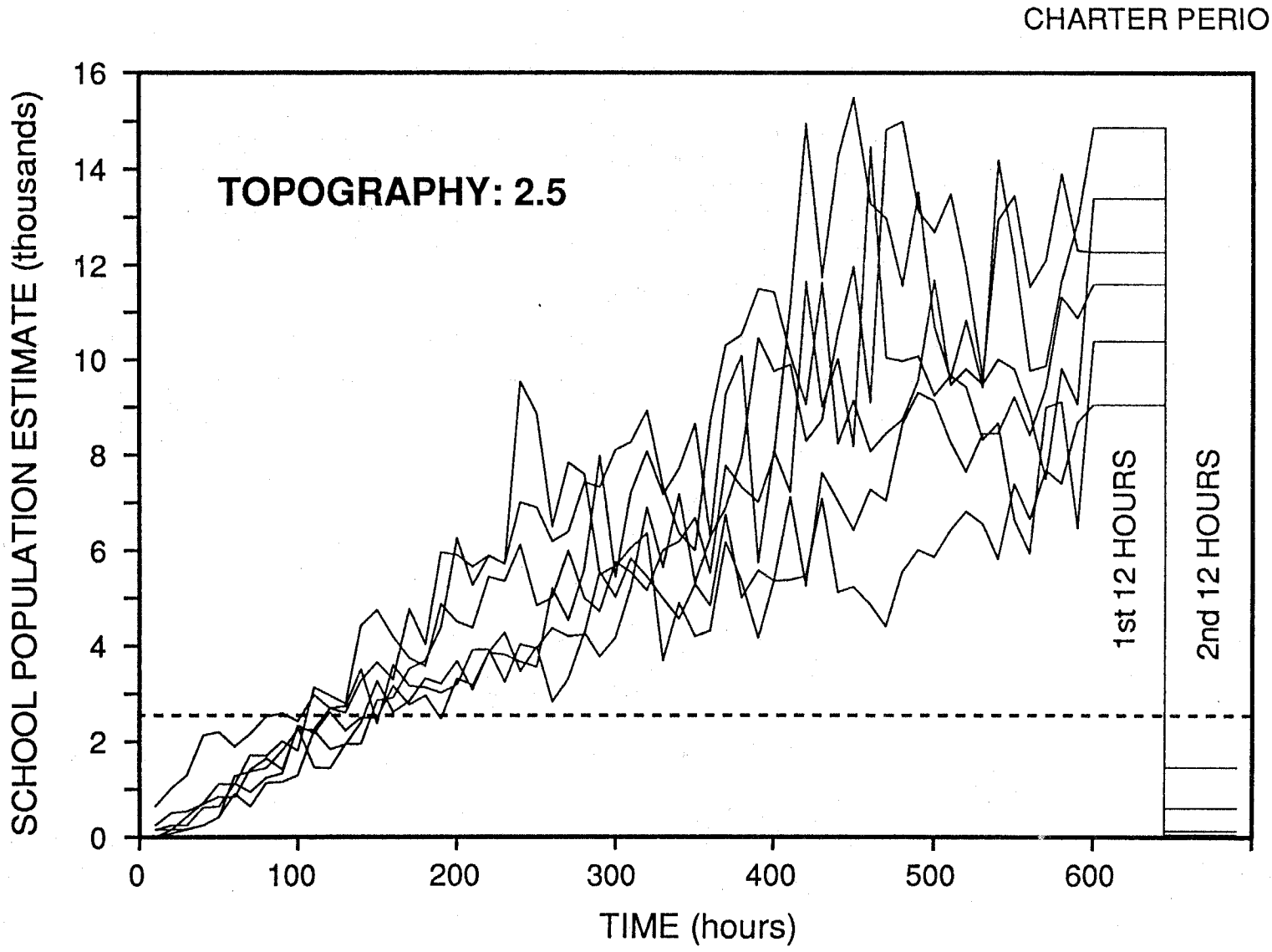

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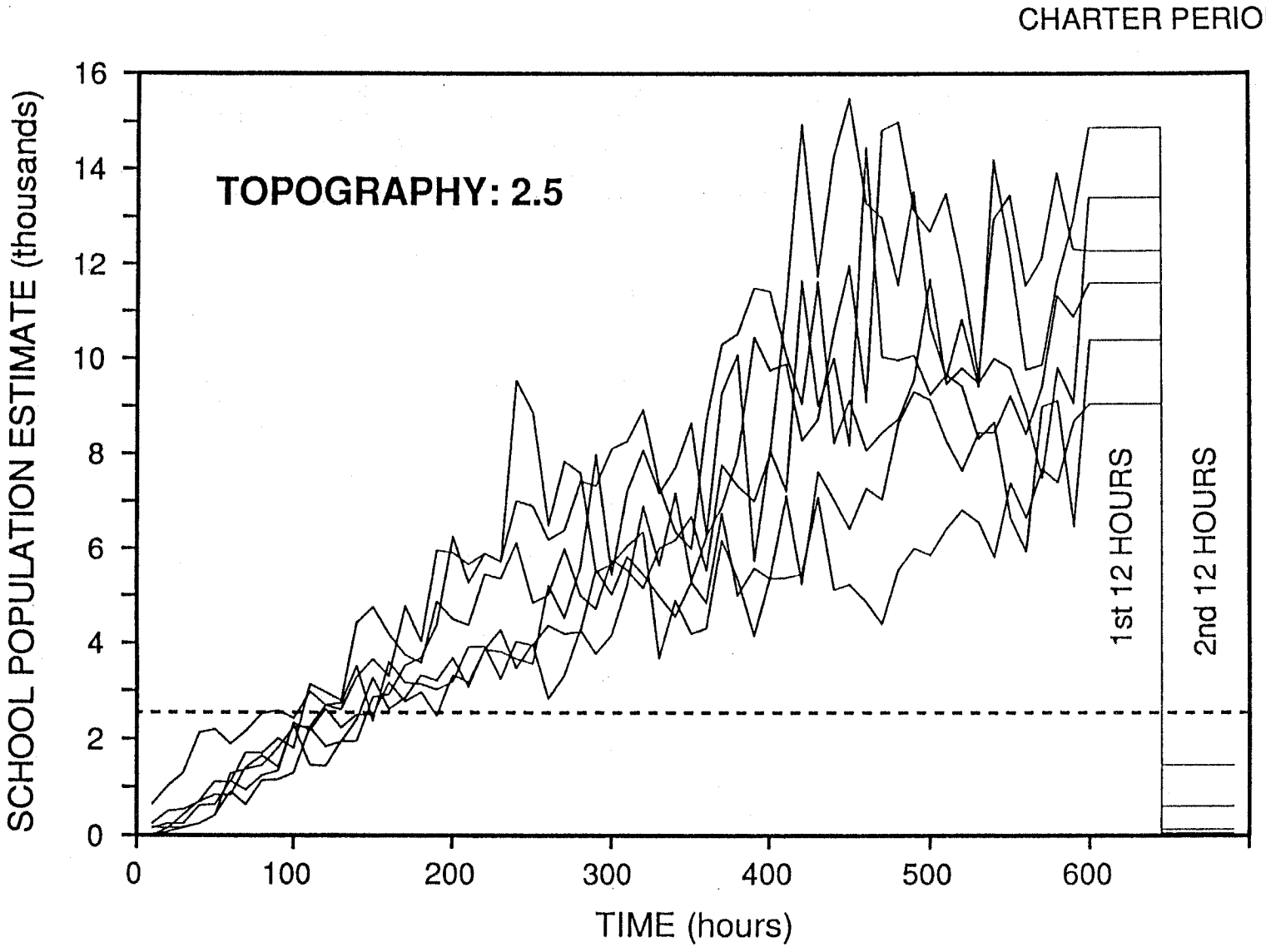

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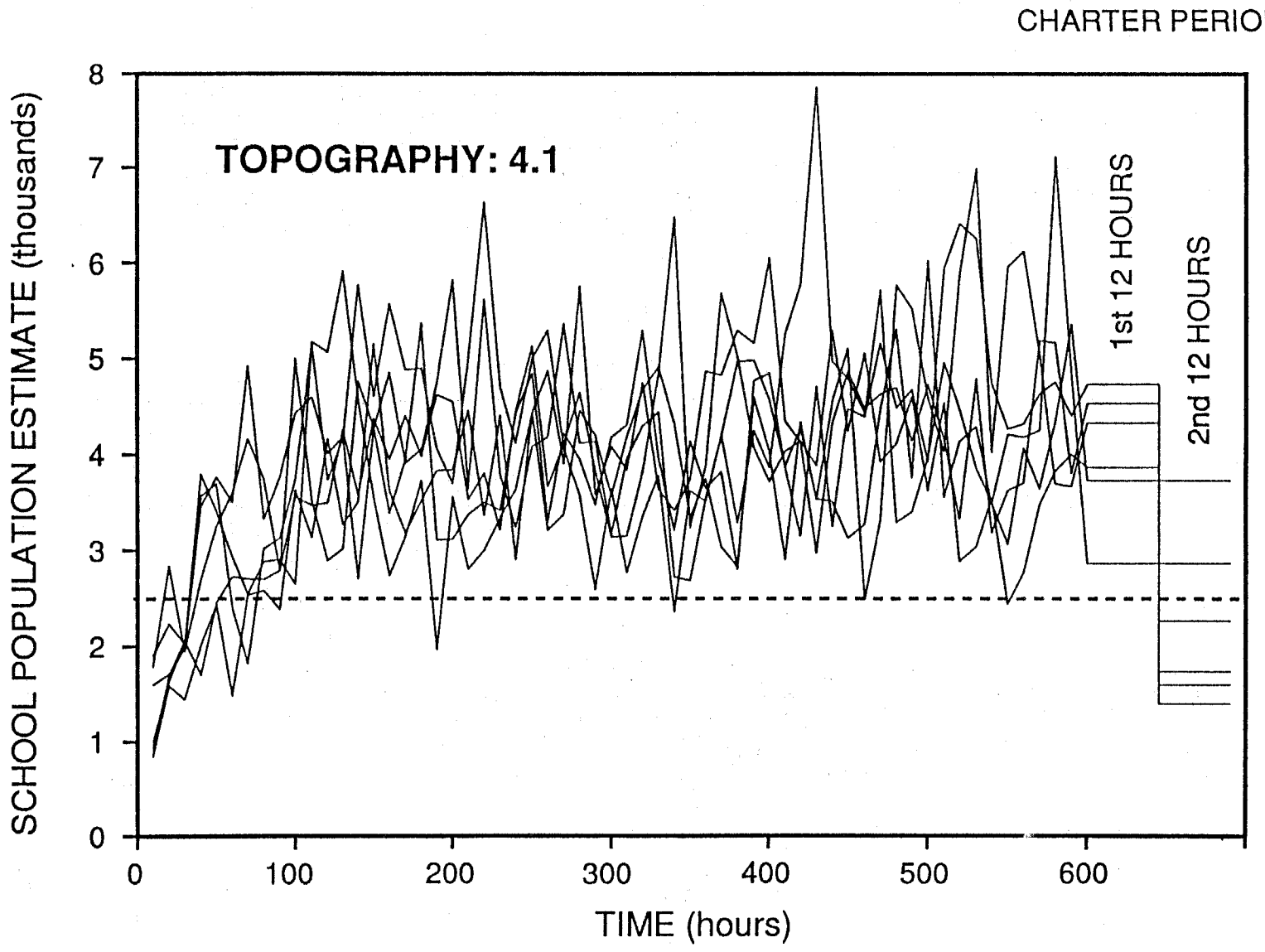

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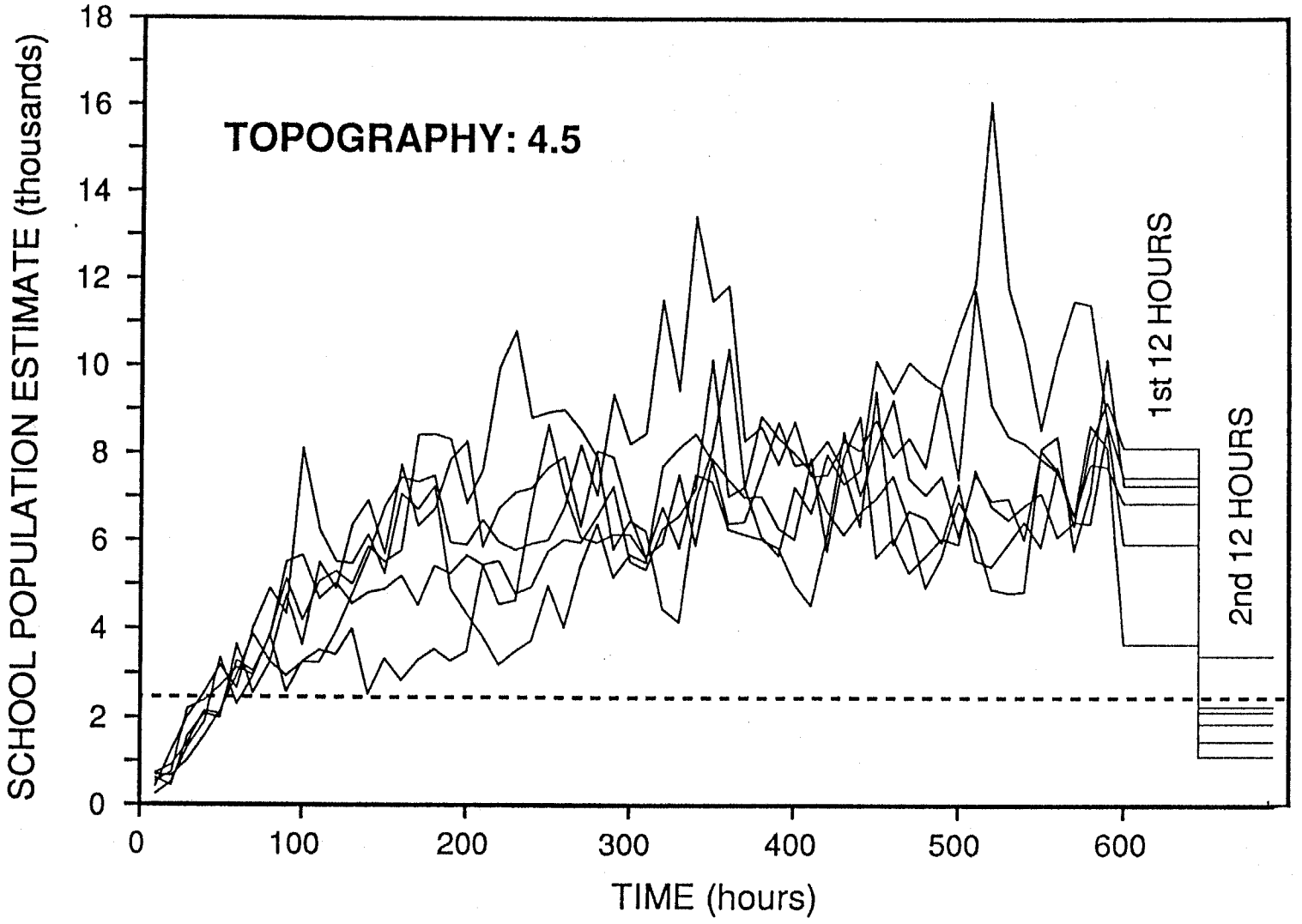

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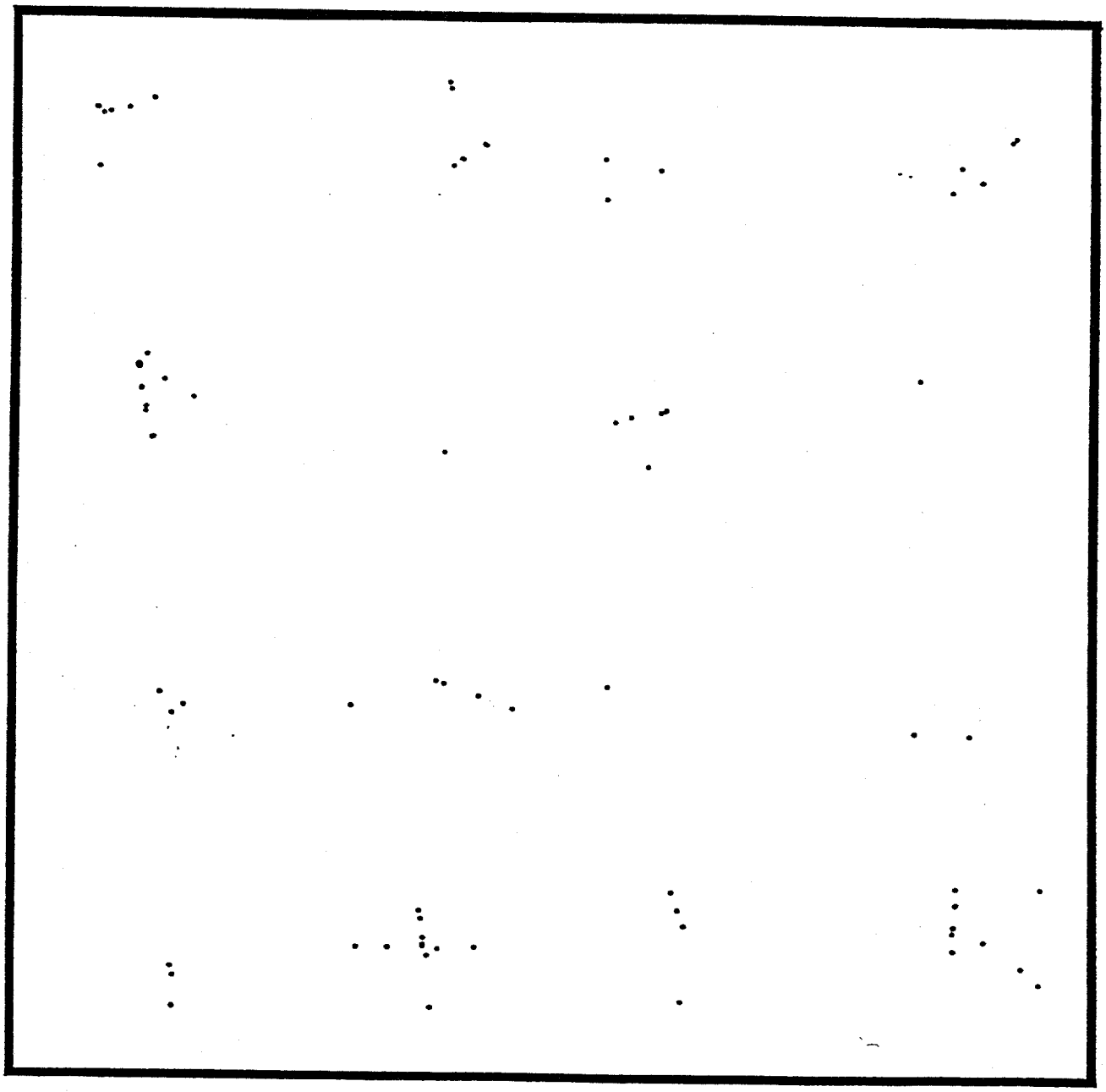

Figure 11. Positions of schools sighted by tuna vessels during 24-hour charter period.

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