NOAA Technical Memorandum NMFS

MAY 1986

DETERMINING FISH MOVEMENTS FROM AN "ARCHIVAL" TAG: PRECISION OF GEOGRAPHICAL POSITIONS MADE FROM A TIME SERIES OF SWIMMING TEMPERATURE AND DEPTH

Paul Smith
Daniel Goodman

NOAA-TM-NMFS-SWFC-60

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

NOAA Technical Memorandum NMFS

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

NOAA Technical Memorandum NMFS

MAY 1986

DETERMINING FISH MOVEMENTS FROM AN "ARCHIVAL" TAG: PRECISION OF GEOGRAPHICAL POSITIONS MADE FROM A TIME SERIES OF SWIMMING TEMPERATURE AND DEPTH

Paul Smith
Southwest Fisheries Center
National Marine Fisheries Service, NOAA
La Jolla, California

Daniel Goodman
Montana State University
Department of Biology
Bozeman, Montana

NOAA-TM-NMFS-SWFC-60

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
Anthony J. Calio, Administrator
National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

DETERMINING FISH MOVEMENTS FROM AN "ARCHIVAL" TAG: PRECISION OF GEOGRAPHICAL POSITIONS MADE FROM A TIME SERIES OF SWIMMING TEMPERATURE AND DEPTH

Paul Smith[1] and Daniel Goodman[2]

Given advances in integrated circuit technology, it is possible to design, build and deploy on a fish a device that would collect and store data on elapsed time, light intensity, pressure (depth) and temperature. From this information it is theoretically possible to reconstruct a series of geographical positions visited by a fish equipped with a device. The tag (proposed by Northwest Marine Technology; discussed by Hunter et al. 1986) would record time of sunset and sunrise from which an estimate of longitude could be directly made. The tag would also record temperature and depth from which estimates of latitude could be deduced. How accurately these estimates can be made is dependent both on the amount and quality of the data collected and how well sea-surface isotherms predict latitude.

The longitude estimate could be made directly from the time of sunrise and sunset, and should readily achieve an accuracy of one degree (Table 1). This requires that the tag be capable of distinguishing differences in sunrise times of at least four minutes. The engineers suggest that this is reasonably easy to attain.

Estimates of latitude would be made from temperature gradient information--both horizontal and vertical. Ideally, the temperature field of the ocean would have sufficient gradient, north to south, that latitude could be established--especially if longitude were known. The objective of this paper is to determine the precision with which latitude could be estimated from simulated temperature and depth records, such as those which could be stored in an archival tag. As an example we use the movements of the Pacific northern bluefin tuna. The range of movements includes an east-west migration corridor with spawning grounds near the western extreme. Bluefin are caught on both sides of the Pacific and in both hemispheres, and their presumed natural history of movements (Bayliff 1980; Yamanaka 1984) are indicated in Figure 1. Although Pacific northern

---

[1] Southwest Fisheries Center
NMFS, NOAA, U.S. Department of Commerce
La Jolla, California 92038, USA

[2] Department of Biology
Montana State University
Bozeman, Montana 59717, USA

[3] The authors wrote this paper to evaluate an idea that developed during a workshop on existing and new technologies that could be employed to measure tuna movements. The workshop was one of a series of three on tuna movements held in 1985. The three workshops were jointly sponsored by the Inter-American Tropical Tuna Commission and the Southwest Fisheries Center of the U.S. National Fisheries Service. For further details regarding the workshops see Hunter et al. 1986.

Table 1. Estimated day length and times of sunrise and sunset in the northern bluefin habitat (from The Nautical Almanac for the Year 1974, U.S. Naval Observatory, Washington, D.C., USA).

	Day length (hr)	Sunrise (GMT[1])	Sunset (GMT)	Day length (hr)	Sunrise (GMT)	Sunset (GMT)	Day length (hr)	Sunrise (GMT)	Sunset (GMT)
115°W Long.		20°N Lat.			25°N Lat.			35°N Lat.	
Mar 21	12.12	1344	0151	12.12	1344	0151	12.12	1344	0151
Jun 20	13.36	1301	0222	13.72	1250	0233	14.55	1225	0258
Sep 20	12.18	1328	0139	12.20	1328	0140	12.24	1326	0141
Dec 20	10.86	1412	0103	10.50	1422	0053	9.67	1447	0028
125°W		25°N			30°N			35°N	
Mar 21	12.12	1424	0231	12.12	1424	0231	12.12	1424	0231
Jun 20	13.72	1330	0313	14.11	1318	0325	14.55	1305	0338
Sep 20	12.20	1408	0220	12.22	1407	0220	12.24	1406	0221
Dec 20	10.50	1502	0132	10.11	1514	0121	9.67	1527	0108
165°W		20°N			35°N			45°N	
Mar 21	12.12	1704	0511	12.12	1704	0511	12.13	1704	0511
Jun 20	13.36	1621	0542	14.55	1545	0618	15.66	1512	0651
Sep 20	12.18	1648	0459	12.24	1646	0501	12.30	1645	0503
Dec 20	10.86	1732	0423	9.67	1807	0348	8.56	1840	0314
165°E		15°N			30°N			50°N	
Mar 21	12.12	2024	0831	12.12	2024	0831	12.13	2023	0831
Jun 20	13.03	1950	0852	14.11	1918	0925	16.42	1809	1034
Sep 20	12.16	2009	0819	12.22	2007	0820	12.33	2004	0824
Dec 20	11.19	2042	0753	10.11	2114	0721	7.81	2223	0612
125°E		20°N			25°N			30°N	
Mar 21	12.12	2144	0951	12.12	2144	0951	12.12	2144	0951
Jun 20	13.36	2101	1022	13.72	2050	1033	14.11	2038	1045
Sep 20	12.18	2128	0939	12.20	2128	0940	12.22	2127	0940
Dec 20	10.86	2212	0903	10.50	2222	0852	10.11	2234	0841

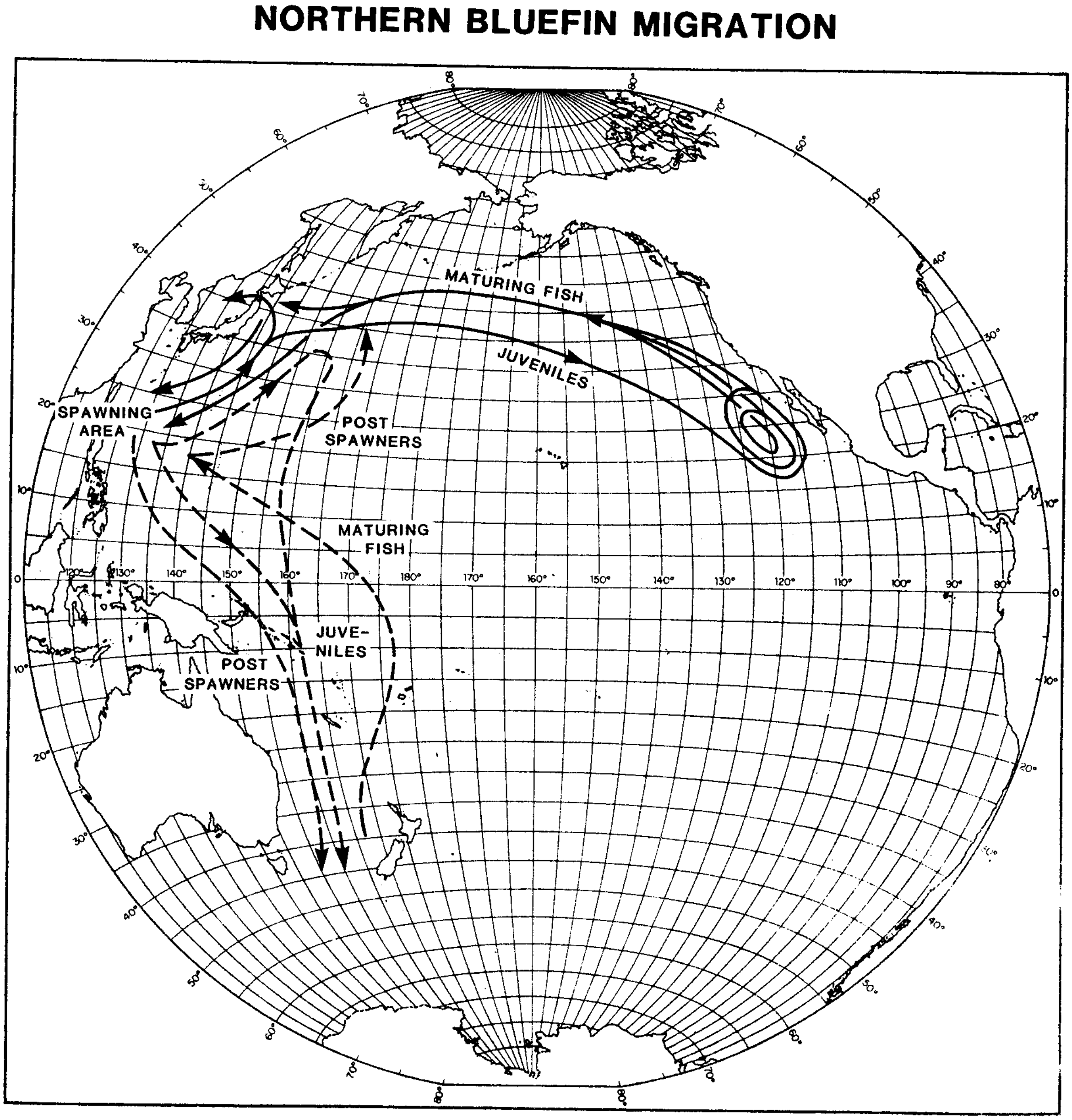
NORTHERN BLUEFIN MIGRATION

Figure 1. A model for northern bluefin migration in the Pacific Ocean (Bayliff 1980).

bluefin have not been tracked using sonic tags, all acoustic tracking studies on tunas, including Atlantic bluefin (Carey and Lawson 1973; Carey and Olson 1982), indicate that they make extensive vertical movements from the surface to the thermocline during the course of a day (Hunter et al. 1986) and are likely to sample most of the depth range on reasonably short intervals (hours).

Initially, we subdivided the east-west migration corridor in the north Pacific into cells 2 degrees on a side; the longitudinal assignment (i.e., assignment to a particular column of cells) was based on the time of sunrise or sunset. Given the identity of the column, the problem is then one of deciding among the approximately 10 cells in that column.

The long-term mean temperatures at selected positions in this field at depths 0, 200 (61 m) and 400 (122 m) ft for February and August are shown in Table 2. In February the horizontal north-south temperature gradient is well developed at the surface, while the vertical gradient is slight (the mixed layer is deep, and the mixing is thorough). Thus the temperature pattern at the surface in February lends itself to extraction of position information.

Table 2. Temperatures (°C) in the North Pacific (from Robinson 1976).

		Temperature (°C)					
		February			August		
	Depth (ft)	0	200	400	0	200	400
Position	Depth (m)	0	61	122	0	61	122
20°N 115°W		22.7	21.3	13.7	26.3	20.0	14.1
25 115		18.3	17.3	12.1	22.0	15.7	12.2
25 125		18.4	18.2	16.8	20.8	18.6	16.3
30 125		16.2	16.1	14.0	19.1	16.4	13.7
35 125		12.7	12.3	10.1	16.7	12.6	9.4
25 135		19.8	19.8	19.2	21.8	20.9	18.7
30 135		18.1	17.9	17.7	21.7	18.8	16.7
35 135		16.2	15.9	13.7	21.1	16.3	14.4
25 145		21.7	21.7	20.6	24.3	22.5	20.0
30 145		19.3	19.3	18.7	23.7	20.7	17.3
35 145		15.6	15.3	15.1	22.2	16.7	13.2
20 155		23.8	23.6	22.2	26.3	24.8	22.2
30 155		19.3	18.9	18.1	25.0	20.9	17.0
40 155		10.9	10.9	10.3	21.5	11.6	9.7

Table 2. (continued)

20	165	24.8	24.6	23.5	27.2	26.0	22.8
35	165	14.6	14.4	13.9	24.4	15.6	13.3
45	165	7.4	7.3	7.2	14.8	7.5	6.7
20	175	25.1	24.6	23.5	27.4	26.6	23.1
30	175	19.0	18.2	17.3	26.4	19.8	17.2
40	175	11.3	11.2	11.1	21.0	12.3	11.3
25°N	175°E	23.1	22.3	20.3	28.4	24.1	20.3
30	175	18.7	18.4	17.8	27.2	20.2	17.3
40	175	10.3	10.3	10.2	21.3	13.5	11.7
20	165	25.9	25.5	23.4	28.4	27.1	23.7
35	165	16.2	16.2	15.7	25.4	18.6	15.5
40	165	8.4	9.3	8.0	20.7	12.7	11.0
20	155	25.8	25.7	23.4	29.1	27.0	23.8
30	155	19.9	19.4	18.6	26.9	19.9	17.5
45	155	1.6	1.4	1.5	13.5	2.3	1.8
15	145	27.6	27.4	25.6	29.6	27.9	26.5
30	145	19.0	18.7	18.3	27.5	22.4	19.2
50	145	-1.7	-1.7	-1.7	12.3	-0.5	-1.0
20	135	25.2	24.8	23.5	29.2	26.8	24.7
30	135	19.1	19.1	19.4	28.8	23.8	20.6
20	125	25.7	24.7	23.0	29.7	28.2	24.1
25	125	22.7	22.4	21.7	29.2	27.1	23.4
30	125	13.0	13.0	-	28.2	19.0	-

In August, however, the horizontal north-south temperature gradient at the surface is less distinct. The depth of the thermocline ranges through the middle depths, 50-200 ft (15-61 m), at this time in a somewhat convoluted pattern. There is reason to suspect that the interannual variation in depth of the thermocline may be appreciable. Thus, the 400 ft depth is probably more suitable for extracting latitudinal information in August.

In general, it would be wise to avoid drawing inferences about latitude from temperature-depth structure at depths near the thermocline, since the position of the thermocline may vary from year to year, and the measurement error in estimating depth creates larger uncertainty where the temperature changes rapidly with depth. The usual depth of the mixed layer at selected positions in the north Pacific is shown in Table 3 at intervals of two months.

Table 3. Mixed layer depth (m) as a function of month and position in the North Pacific Ocean (from Robinson 1976).

	Mixed layer depth (m)					
Position	Feb	Apr	Jun	Aug	Oct	Dec
20°N 155°W	104	99	70	69	73	94
30	122	76	30	34	46	76
40	>122	107	15	<15	46	84
20°N 155°E	101	70	46	46	52	88
30	116	91	18	<15	46	76
45	>122	>122	24	<15	23	91

In Table 4 we show, for each of the longitudes in Table 2, the mean surface temperature, the mean horizontal north-south gradient of surface temperature, and the mean vertical gradient, over the interval 0 to 200 ft, for two or three latitudinal stations within the migration corridor at this longitude. All are based on the long-term February mean. For most of the corridor we can count on a latitudinal gradient of about 0.667°C per degree of latitude and about 0.0015°C per foot of depth.

In Table 5 we show, for each of the longitudes in Table 2, the mean temperature at 400 ft, the mean gradient of this temperature with respect to latitude, and the mean gradient over the interval 200 to 400 ft of the temperature with respect to depth, for the two or three latitudinal stations within the migration corridor at this longitude. All the data are are based on the long-term August mean. For most of the corridor we can expect a latitudinal gradient of about 0.5°C per degree of latitude, and about 0.015°C per foot (0.049°C per meter) of depth.

These temperatures from the mean field, at the appropriate depth for each season, will be used as reference temperatures to infer latitudinal position from observed temperature (as recorded in an archival tag). Because of interannual variation, the actual temperature at a given position may depart somewhat from the long-term mean we are using as a reference. Table 6 shows estimates of the extent of the interannual standard deviation in temperature at depth for various stations in the migration corridor. For example, the standard deviation of the February surface field is 1.5°C, and for August the 400-ft field has a standard deviation of 0.6°C.

A second source of deviation of the observed temperature from the reference temperature is measurement error of the depth estimate. We assume a standard deviation of 30 ft (9 m). Multiplying this value by the appropriate depth-temperature gradient gives an estimate of the error in the temperature estimate, due to error of the depth estimate. It is 0.045°C for February at the surface, and 0.45°C for August at 400 ft.

Table 4. Characteristics of the sea-surface temperature field in portions of the Pacific bluefin tuna migration corridor in February. Mean temperature in °C is averaged over latitude at the given longitude. The gradient with latitude is in degrees of latitude per °C, averaged over the 2 or 3 latitudes of Table 2; the gradient with depth is in °C per foot x 100, averaged over the interval from the surface to 200 ft.

	°E Longitude						°W Longitude						
	125	135	145	155	165	175	175	165	155	145	135	125	115
Mean surface temperature (°C)	20.5	22.2	15.0	15.8	16.8	17.4	18.5	15.6	18.0	18.9	18.0	15.8	20.5
Gradient with latitude (Lat°/°C)	0.8	1.6	1.2	1.0	1.1	1.2	1.4	1.4	1.6	1.6	2.8	1.8	1.1
Gradient with depth (°C/ft x 100)	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.6

Table 5. Characteristics of the 400 ft depth water temperature field in portions of the Pacific bluefin tuna migration corridor in August. Mean temperature in °C is averaged over latitude at the given longitude. The gradient with latitude is in degrees of latitude per °C, averaged over the 2 or 3 latitudes of Table 2;the gradient with depth is in the °C per foot x 100 averaged over the interval from 200 to 400 ft.

	°E Longitude						°W Longitude						
	125	135	145	155	165	175	175	165	155	145	135	125	115
Mean 400 ft temperature (°C)	23.8	22.6	14.9	14.4	16.7	16.4	17.2	14.3	16.3	16.8	16.6	13.1	13.2
Gradient with latitude (Lat°/°C)	7.1	2.4	1.3	1.1	1.6	1.7	1.7	1.6	1.6	1.5	2.3	1.4	2.6
Gradient with depth (°C/ft x 100)	2.0	1.3	0.9	1.0	1.4	1.4	1.2	1.0	1.4	1.6	1.0	1.4	2.4

Table 6. Climatology of sea surface temperature in the North Pacific Ocean (from Fleet Numerical Oceanographic Center climatological data base).

Position		MSq[1]	SubSq[2]	February			August		
				N[3]	SST[4]	S.D.[5]	N	SST	S.D.
20°N	115°W	084	05	5	22.0	2.1	12	25.9	1.1
25	115	084	55	18	18.2	1.4	30	22.7	1.9
35	115	120	49	158	14.0	1.0	143	18.2	3.1
25	125	085	55	16	18.4	0.9	15	21.3	0.9
30	125	121	05	24	16.6	1.6	32	18.9	1.3
35	125	121	55	70	13.5	1.5	126	17.6	1.7
25	135	086	55	10	20.0	0.8	12	22.3	1.1
30	135	122	05	147	18.0	1.0	157	21.4	1.3
35	135	122	55	109	15.0	1.2	71	20.7	1.9
25	145	087	55	60	21.6	1.3	42	24.1	1.2
30	145	123	05	69	18.8	1.1	32	23.3	1.0
35	145	123	55	65	15.6	1.3	38	22.8	1.5
20	155	088	05	21	23.4	0.9	21	26.4	1.0
30	155	124	05	100	19.0	1.4	32	24.4	1.7
40	155	160	05	35	11.2	1.9	53	21.1	2.1
20	165	089	05	41	24.6	0.8	44	27.2	1.2
35	165	125	55	64	14.3	1.5	51	24.5	1.5
45	165	161	55	44	7.1	1.9	48	15.0	1.8
20	175	090	05	44	25.1	1.0	41	28.2	1.1
30	175	126	05	131	18.3	1.2	43	25.9	1.2
40	175	162	05	35	11.0	1.1	53	20.6	2.3
25°N	175°E	091	55	65	2.25	2.0	42	27.5	0.9
30	175	127	05	144	18.1	1.4	74	26.3	1.2
40	175	163	05	26	10.4	1.7	55	20.0	2.1
20	165	092	05	17	25.6	1.0	17	29.1	0.6
35	165	128	55	77	15.4	2.4	65	25.2	1.4
40	165	164	05	46	10.2	2.3	52	20.5	2.1
20	155	093	05	49	26.0	1.0	47	29.6	0.8
30	155	129	05	81	18.4	1.4	58	27.2	1.2
45	155	165	55	33	2.2	1.4	54	12.0	1.8
15	145	058	55	19	26.9	1.0	40	29.6	0.8
30	145	130	05	31	18.3	1.1	42	28.0	1.2

Table 6. (continued)

20	135	095	05	11	25.9	1.3	25	28.8	1.8
30	135	131	05	163	18.8	2.0	231	28.4	1.0
35	135	131	55	2	12.8	5.5	8	26.3	1.8
20	125	096	05	44	24.7	1.6	95	29.1	1.3
25	125	096	55	84	22.0	1.7	113	28.8	1.3
30	125	132	05	53	12.8	3.0	61	28.2	1.0

[1] MSq=Marsden square.

[2] SubSq= subsquare.

[3] N= number of observations.

[4] SST= sea-surface temperature.

[5] S.D.= standard deviation.

We will presume that the error in measurement of temperature is small in comparison to the two previous sources of error.

Then, the total variance in observed temperature relative to the reference temperature for that position is the sum of the interannual temperature variance and the variance due to depth estimation error. Expressed as a standard deviation, this will be about 1.5°C for the surface in February, and about 0.75°C for the 400-ft depth in August.

Imagine that we carried out the estimation of latitude by asking which cell, of the column corresponding to the longitude already established by time of sunrise, had a reference temperature closest in value to the observed temperature. Then the probability of correct assignment to cell by latitude would be the probability of correct assignment to cell by latitude within D/2 degrees of the reference temperature in the correct cell, where D represents the difference in temperature between rows (latitudes at the resolution of cells) in the grid. For a given cell size, we may compute D from the latitudinal gradient in temperature (e.g., for a 5-degree area at the surface in February, D is 3.33°C, and for the same resolution in August at 400 ft, D is 2.5°C).

Assuming that the disturbance in observed temperature relative to the reference temperature is Gaussian, with zero mean and with a standard deviation as computed from the interannual variation and the error in depth estimation, we can readily compute the probability of correct latitude assignment by integrating the appropriate normal density from -D/2 to +D/2. For example, with a grid of 5-degree areas, the probability of correct assignment is 73% for February and 91% for August.

A 73% probability of correct position with 5-degree resolution probably is not very useful, while a 91% probability of correct position is borderline.

Inspection of the magnitudes of component errors that go into the calculation of the total standard deviation of observed temperature relative to the reference temperature for that depth and position, according to the formula

$$s_t = (s^2_e + s^2_d)^{0.5}$$

where s_e is the environmental component and s_d is the depth error component, shows that the total standard deviation is dominated by the environmental variance owing to interannual differences. Thus improvement in the accuracy of positioning must rest on reduction of the effect of this error.

The interannual variation probably can be represented as an effect with a substantial temporal autocorrelation (at lags of at least a month) and with substantial spatial autocorrelation (perhaps on a scale of tens of degrees of latitude and longitude). Therefore, it should be feasible to calibrate the reference temperature field being used for a particular period (season, year) from a handful of actual measurements of temperature. For surface temperature the correction is readily obtained from satellite determinations of sea-surface temperature. For temperatures at depth, we would require temperature profile data, perhaps from ships of opportunity or from a network of buoys. Table 7 shows temperature readings from cruises at specific times in the area of interest (McGowan and Williams 1973; Hayward and McGowan 1985) indicating the potential for calibration on the basis of the smoothness of the latitudinal temperature gradient at any time.

Imagine that the calibration of the temperature reference field reduced the effective uncertainty in temperature at position to a standard deviation of 0.25°C (corresponding to a reduction to 1/6 of the standard deviation owing to interannual variation for surface temperature in February, or slightly less than 1/2 of the standard deviation owing to interannual variation for temperature at 400 ft in August). This value for s_t yields a prediction of 99% correct assignment at a resolution of 2-degree squares for February, and 95% correct assignment at a resolution of 5-degree squares for the August situation. For August, further reduction of the error owing to interannual variation is not valuable, since at about this level the depth measurement error component begins to dominate. Conceivably, the effect of depth measurement error could be reduced through averaging over multiple observations. Regardless, the above accuracies for positioning should be acceptable for research purposes.

We conclude that the archival tag appears to offer considerable potential for determining historical fish position, inferring longitude from time of sunrise and sunset, and inferring latitude from temperature at depth relative to a reference field. The resolution achievable using simple long-term mean temperatures for the reference field does not appear very attractive. By contrast the resolution achievable by correcting the reference field on the basis of some calibration measurements in real time appears to be extremely good.

Table 7. Temperature (°C) at 200 meters as a function of latitude at 155°W.

	Cruise				
Latitude	Ursa Major[1] 9/64	Zetes I[1] 1/66	Fiona[2] 10/80	Mean	S.D.
26°N	20.0	15.0	15.0	16.7	2.9
27	18.8	14.7	15.0	16.2	2.3
28	16.2	15.7	13.8	15.2	1.3
29	15.4	13.9	13.5	14.3	1.0
30	14.3	12.8	12.3	13.1	1.0
31	13.7	12.7	12.5	13.0	0.6
32	13.3	12.3	12.1	12.6	0.6
33	12.5	12.6	11.6	12.2	0.6
34	11.9	12.0	11.6	11.8	0.2
35	11.7	11.9	11.3	11.6	0.3
36	11.0	10.9	10.7	10.9	0.2
37	10.8	11.2	9.9	10.6	0.7
38	10.6	11.1	9.9	10.5	0.6
39	10.5	11.2	9.5	10.4	0.9
40	10.3	10.2	9.3	9.9	0.6
41	10.2	10.2	9.0	9.8	0.7
42	9.2	9.5	8.3	9.0	0.6
43	9.0	8.7	7.9	8.5	0.6
44	8.3	7.7	7.2	7.7	0.6

[1] McGowan and Williams 1973.

[2] Hayward and McGowan 1985.

ACKNOWLEDGEMENTS

James D. Ryan and Lawrence E. Eber provided crucial technical assistance in acquiring the data and programming. We also acknowledge Andy Dizon and Carol Kimbrell's extensive editorial help in bringing this note to completion. The expense of programming and computation was borne by Jay Barlow and John Hunter. We thank Celeste Santos-Methot for organizational assistance.

LITERATURE CITED

BAYLIFF, W.H.
1980. Synopsis of biological data on the northern bluefin tuna, Thunnus thynnus (Linnaeus, 1758), in the Pacific Ocean. Inter-Amer. Trop. Tuna Comm., Spec. Rep. 2:261-293.

CAREY, F.G., and K.D. LAWSON.
1973. Temperature regulation in free-swimming bluefin tuna. Comp. Biochem. Physiol. 44A:375-392.

CAREY, F.G., and R.J. OLSON.
1982. Sonic tracking experiments with tunas. Int. Comm. Conserv. Atl. Tunas Collect. Vol. Sci. Pap., 17:458-466.

HAYWARD, T.L., and J.A. McGOWAN.
1985. Spatial patterns of chlorophyll, primary production, macrozooplankton biomass, and physical structure in the central North Pacific Ocean. J. Plank. Res. 7:147-167.

HUNTER, J.R., A.W. ARGUE, W.H. BAYLIFF, A.E. DIZON, A. FONTENEAU, D. GOODMAN, and G.R. SECKEL.
1986. The dynamics of tuna movements: an evaluation of past and future research. FAO Fish. Tech Pap. (In press).

LaVIOLETTE, P.E., and S.E. SEIM.
1969. Monthly charts of mean, minimum, and maximum sea surface temperature of the North Pacific Ocean. Nav. Oceanog. Off., Spec. Pub. No. 123, 62 p.

McGOWAN, J.A., and P.M. WILLIAMS.
1973. Oceanic habitat differences in the North Pacific. J. Exp. Mar. Biol. Ecol. 12:187-217.

ROBINSON, M.K.
1976. Atlas of the North Pacific Ocean monthly mean temperatures and mean salinities of the surface layer. Nav. Ocean. Off. Ref. Pub. 2, 19 p., 173 fig.

U.S. NAVAL OBSERVATORY.
1972. The Nautical Almanac for the Year 1974. U.S. Gov. Print. Off., Washington, D.C.

YAMANAKA, H.
1984. The relationship between El Niño episodes and fish migration and yields in the western Pacific. Trop. Ocean-Atmos. Newsletter 25: 2-4.

RECENT TECHNICAL MEMORANDUMS

Copies of this and other NOAA Technical Memorandums are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22167. Paper copies vary in price. Microfiche copies cost $4.50. Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Center are listed below:

NOAA TM-NMFS SWFC

50 Hawaiian Monk Seal observations on French Frigate Shoals, 1980.
P.A. JOHNSON and B.W. JOHNSON
(October 1984)

51 Estimating dolphin juvenile survival rates from the proportion of calves nursing.
T. POLACHECK
(October 1984)

52 Operational plan for NMFS albacore program.
R.H. PARRISH, et al.
(May 1985)

53 Albacore fishing and windspeed.
P.N. SUND
(June 1985)

54 Proceedings of the workshop on the fate and impact of marine debris, 27-29, November 1985, Honolulu, Hawaii.
R.S. SHOMURA and H.O. YOSHIDA (Editors)
(August 1985)

55 The Hawaiian Monk Seal and Green Turtle on Necker Island, 1983.
R.J. MORROW and E.K. BUELNA
(November 1985)

56 Proportions of species of dolphin in the eastern tropical Pacific.
J. BARLOW and R.S. HOLT
(January 1986)

57 A budget simulation model for west coast albacore trollers.
S.F. HERRICK and K.L. CARLSON
(February 1986)

58 The Hawaiian Monk Seal on Lisianski Island: 1983.
T.C. JOHANOS and A.K.H. KAM
(February 1986)

59 Hawaiian Monk Seal observations and captive maintenance project at Kure Atoll, 1981.
W.G. GILMARTIN, R.J. MORROW, and A.M. HOUTMAN
(March 1986)