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NEARSHORE SURFACE CURRENT PATTERNS IN THE TSITSIKAMMA NATIONAL PARK, SOUTH AFRICA

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The pattern of surface currents in the Tsitsikamma National Park, South Africa, was studied with holey-sock drogues released in batches of up to four at a time, from 1996 and 1998. Drogues were left to drift for either 6 or 24 h, while recording position and time. The majority of drogue movements were longshore, either eastward or westward; they usually travelled with similar direction and velocity. In most instances, westward movements were slightly offshore and were sometimes associated with a rise in the thermocline. Eastward movements were, on average, slightly slower, with an onshore component, sometimes associated with a lowering of the thermocline. The remaining trials showed some variability between drogues and were characterized by reduced velocity and unstable direction, indicating either the presence of horizontal turbulence or a current reversal. Current and wind were poorly correlated. Current directions were sustained for at least four days, indicating that short-lived ichthyoplankton, originating in the 70-km park, may be dispersed beyond its boundaries.

Key words: currents, drogues, larval dispersal, marine protected areas

One of the most important functions of the Tsitsikamma National Park (TNP), a marine protected area, is the protection of stocks of commercially important reef fish of the family Sparidae. Reef fish are considerably more abundant (per unit area) and attain greater ages in the TNP than in equivalent areas where fishing is allowed (Buxton and Smale 1989, Buxton 1993). Many of these reef fish are depleted below commonly regarded threshold reference points, and are therefore classed as overexploited (Griffiths 1997). The strong gradient in density of spawner-biomass between the protected and unprotected fish stocks has lead to the hypothesis that fish in the TNP may be seeding stocks in adjacent areas. One possible mechanism for this enhancement is the passive drift of eggs and larvae from the reserve to adjacent areas, where they may recruit and become vulnerable to capture by linefishers.

The drift hypothesis is being investigated by two parallel investigations. Tilney *et al*. (1996) and Wood (1998) described the temporal and spatial distribution of ichthyoplankton in the TNP. It is commonly presumed that sparid eggs and larvae are planktonic, with little swimming capacity in the early stages of life, although recent studies have shown that reef fish larvae are capable of some control over their dispersal (Warner *et al*. 2000). Notwithstanding the possibility of positional control by ichthyoplankton, current patterns are likely to influence the spatial distribution of settled larvae that originate in TNP. The second component of this research is therefore aimed at providing a broad description of the current patterns in the vicinity of TNP.

Tilney *et al*. (1996) measured currents with an acoustic current meter moored near the seabed (48 m deep) directly off the Elands River in the TNP. They obtained a 200-day time-series, from which it was apparent that coastal-trapped waves were the dominant physical process influencing currents. The tidal contribution was small. Upwelling in spring and summer produced onshore compensation currents towards the coast when winds had an easterly component. In winter, there were regular longshore current oscillations with periods of between two and four days.

Tilney *et al*. (1996) suggested that wind might play a more important role in plankton transport in the surface mixed layer, particularly during upwelling events when surface water is displaced offshore. Many fish eggs, including those of sparids, float. The mesoscale upwelling events off the Tsitsikamma coast have the potential to displace plankton large distances from their origin.

This study reports on surface current measurements estimated from the release of surface drogues off the Storms River mouth from 1996 and 1998. The study was initiated to complement moored ADCP current measurements, reported by Roberts and van den Berg (in press). However, ADCP measurements cannot provide data for the surface mixed layer. The drogues tracked water masses in the TNP, and so

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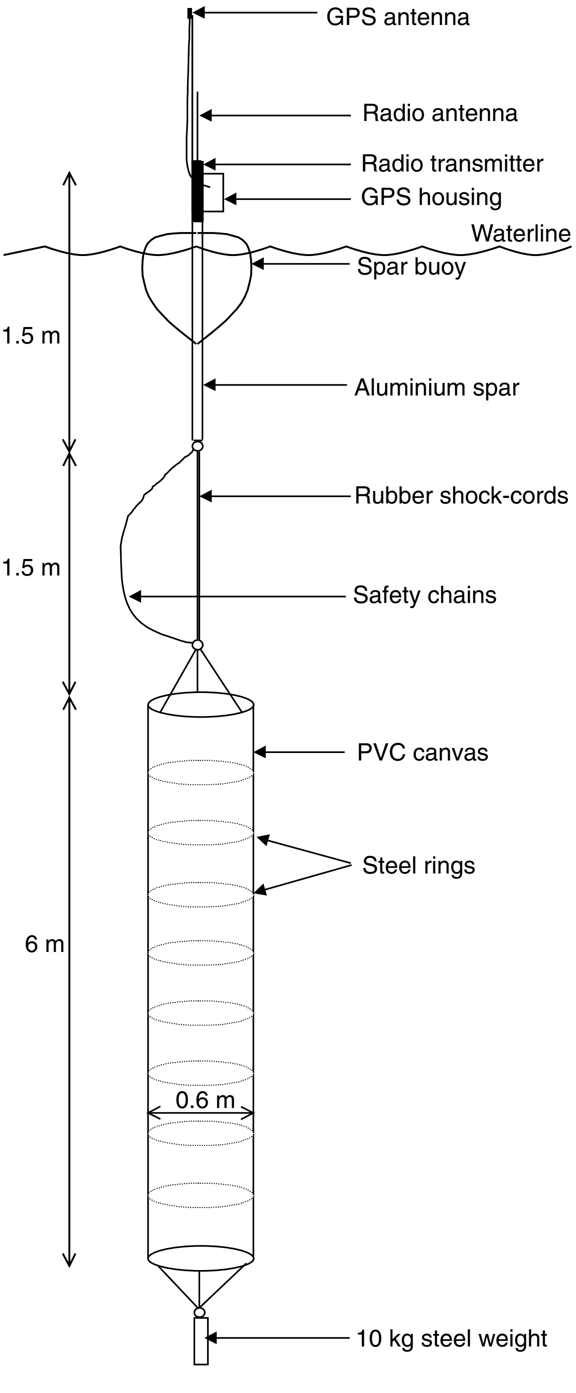

Fig. 1: Diagrammatic view of the holey-sock drogue. Not shown are the 20-cm diameter holes cut into the PVC canvass

Table I: Schedule of drogue releases. The drogues trials for which GPS tracks are available are listed under Trials (see text for further details)

Date	Trials	Number of hours tracked	Tracks
11 Apr. 1996	3(a)	6	
12 Apr. 1996	4(a)	6	
13 Apr. 1996	5(a)	6	
14 Apr. 1996	6(a,b,c,d)	6	
15 Apr. 1996	7(a,b,c,d)	6	a,b
20 Jul. 1996	8(a,b,c,d)	6	a,c,d
21 Jul. 1996	9(a,b,c,d)	6	a,b,c
22 Jul. 1996	10(a,b,c)	6	a,b,c
23 Jul. 1996	11(a,b,c)	6	a,b,c
14 Sep. 1996	16(a)	6	a
15 Sep. 1996	17(a,b)	6	a,b
30 Sep. 1996	12(a,b,c,d)	6	b,c,d
2 Oct. 1996	13(a,b)	6	a,b
3 Oct. 1996	14(a,b)	6	a,b
4 Oct. 1996	15(a,b)	6	a,b
5 Nov. 1996	18(a,b,c,d)	6	b,c,d
6 Nov. 1996	19(a,b,c,d)	6	a,b,c,d
14 Jan. 1997	20(a,b)	6	a,b
15 Jan. 1997	21(a,b)	6	a,b
16 Jan. 1997	22(a,b,c,d)	6	a,b,c,d
17 Jan. 1997	23(a,b,c,d)	6	a,b,c,d
13 Feb. 1998	24(a,b,c,d)	6	a,b,c,d
14 Feb. 1998	25(a,b,c,d)	6	a,b,c,d
15 Feb. 1998	26(a,b,c)	6	a,b,c
16 Feb. 1998	27(a,b,c)	24	c
12 Oct. 1998	28(a,b)	24	a
13 Oct. 1998	29(a)	24	a
14 Oct. 1998	30(a,b)	24	a,b
7 Dec. 1998	31(a,b)	24	b
8 Dec. 1998	32(a,b)	24	b
9 Dec. 1998	33(a)	24	a
10 Dec. 1998	34(a)	2	

provided information on surface transport that the fixed instruments are also not able to do.

MATERIAL AND METHODS

Drogue design

A holey-sock design (Niiler *et al.* 1995) was used to build four surface drifters that each housed a GPS unit and a radio beacon (Fig. 1). A spar buoy was sleeved over a spar in which an internal battery-powered radio beacon (Novatech RF-700C) was housed. A Garmin GPS-45 unit was housed in a sealed plastic box clamped to the spar, above the buoy. The GPS antenna was raised to a level 50 cm above the top of the radio beacon antenna. This distance proved necessary to avoid radio interference with satellite signals.

The drogue was a 6-m "sock" of PVC canvas held open by 11 stainless steel rings of 0.6 m diameter. The

Table II: Details of westward displacements. Horizontal lines group drogues run on consecutive days

Drogue	Date	Dis-place-ment	Speed (cm s^{-1})	Direction (degrees)	Δz (%)	SST (°C)	ΔSST (°C)	Thermocline depth (m)	Tidal phase (min.)	Tidal amplitude (m)	Wind direction of origin (degrees)	Wind velocity (m s^{-1})
3	11 Apr. 1996	618	5.8	289	-16	14.1	-0.5	N.A.	-61	0.69	50	4.0
4	12 Apr. 1996	3 777	19.8	269	18	13.6	-2.8	N.A.	-101	0.69	60	5.2
5	13 Apr. 1996	5 881	21.9	249	48	10.8	-0.8	N.A.	-259	0.93	80	2.6
8A	20 Jul. 1996	7 962	42.4	278	42	15.8	0.2	N.A.	129	1.21	270	4.3
8B	20 Jul. 1996	7 341	40.9	282	8	15.8	0.2	N.A.	156	1.21	270	4.3
8C	20 Jul. 1996	6 585	36.6	282	-3	15.8	0.2	N.A.	166	1.21	270	4.3
8D	20 Jul. 1996	4 978	26.4	284	-9	15.8	0.2	N.A.	181	1.21	270	4.3
9A	21 Jul. 1996	6 491	30.8	282	-7	16.0	-0.1	N.A.	224	0.98	260	2.2
9B	21 Jul. 1996	6 313	30.2	283	-7	16.0	-0.1	N.A.	237	0.98	260	2.2
9C	21 Jul. 1996	5 367	26.0	286	-9	16.0	-0.1	N.A.	251	0.98	260	2.2
10A	22 Jul. 1996	8 160	35.1	278	40	15.9	-0.1	>40 m	205	0.93	110	4.3
10B	22 Jul. 1996	8 023	35.0	278	14	15.9	-0.1	>40 m	220	0.93	110	4.3
10C	22 Jul. 1996	7 341	31.5	290	7	15.9	-0.1	>40 m	236	0.93	110	4.3
11A	23 Jul. 1996	8 290	40.9	273	47	15.8	-2.6	20–30 m	121	0.77	110	6.3
11C	23 Jul. 1996	8 368	41.5	269	1	15.8	-2.6	20–30 m	161	0.77	110	6.3
14A	3 Oct. 1996	10 441	44.3	278	N.A.	16.9	-0.2	N.A.	113	0.95	170	1.4
14B	3 Oct. 1996	12 121	57.9	279	N.A.	16.9	-0.2	N.A.	126	0.95	170	1.4
15A	4 Oct. 1996	10 432	51.6	275	N.A.	16.7	0.1	N.A.	90	0.59	270	3.5
15B	4 Oct. 1996	8 008	40.4	278	N.A.	16.7	0.1	N.A.	109	0.59	270	3.5
19A	6 Nov. 1996	3 819	18.6	232	N.A.	17.6	-0.6	>40 m	-209	0.67	100	5.0
19B	6 Nov. 1996	3 466	16.9	225	N.A.	17.6	-0.6	>40 m	-199	0.67	100	5.0
19C	6 Nov. 1996	3 660	17.2	222	N.A.	17.6	-0.6	>40 m	-188	0.67	100	5.0
19D	6 Nov. 1996	4 519	20.9	228	N.A.	17.6	-0.6	>40 m	-178	0.67	100	5.0
20A	14 Jan. 1997	6 414	27.6	280	2	21.4	0.0	30–40 m	140	1.49	260	4.0
20B	14 Jan. 1997	6 446	27.8	278	0	21.4	0.0	30–40 m	158	1.49	260	4.0
21A	15 Jan. 1997	16 003	49.2	278	34	21.4	0.0	20–30 m	-16	1.21	250	3.1
21B	15 Jan. 1997	16 746	50.8	276	9	21.4	0.0	20–30 m	-7	1.21	250	3.1
22A	16 Jan. 1997	3 181	15.3	278	2	22.1	0.7	30–40 m	-1	0.94	270	5.4
22B	16 Jan. 1997	5 274	24.8	281	0	22.1	0.7	30–40 m	11	0.94	270	5.4
22C	16 Jan. 1997	5 384	25.2	287	-9	22.1	0.7	30–40 m	23	0.94	270	5.4
22D	16 Jan. 1997	5 581	26.1	293	-19	22.1	0.7	30–40 m	36	0.94	270	5.4
27A	16 Feb. 1998	20 610	24.9	265	91	9.0	-0.2	N.A.	-99	1.49	70	2.3
27B	16 Feb. 1998	21 323	25.6	265	43	9.0	-0.2	N.A.	-92	1.49	70	2.3
27C	16 Feb. 1998	22 025	26.3	265	15	9.0	-0.2	N.A.	-85	1.49	70	2.3
33A	9 Dec. 1998	12 082	13.4	261	N.A.	12.4	0.0	10–20 m	-254	1.06	230	2.6
34A	10 Dec. 1998	1 597	21.3	269	N.A.	12.4	-1.9	Surface	-265	0.48	90	5.6

Δz = change in depth of water along drogue track, SST = sea surface temperature, ΔSST = change in SST over 24 h sock was perforated with 20 holes (each of 200-mm diameter) to increase its drag coefficient. A 10-kg steel weight was tethered to the bottom ring to keep the drogue taut and vertically orientated. The top ring of the drogue was tethered to the spar with a chain and a double rubber shock cord designed to dampen the action of waves on the drogue. The drogue effectively integrated currents between 2 and 8 m deep.

Because the wind slip on the drogues was not measured, the results of the experiments done by Niiler *et al*. (1995) were used. The ratio of the drag of the buoy and spar to that of the drogue was 40:1. On their models, which were slightly larger, Niiler *et al*. (1995) found that this ratio limited wind slip to <1 cm s^{-1} for a wind speed of 10 m s^{-1}.

Drogue trials

Owing to logistic constraints, drogue trials were conducted opportunistically to coincide with other fieldwork schedules between 1996 and 1998 (Table I). The basic experiment consisted of four drogues drifting simultaneously for approximately 6 h. Drogues were released sequentially along a transect off the Storms River Mouth at nominal distances of 1, 1.5, 2 and 2.5 miles from the shore on longitude 23°53.85´E. Release latitudes were 34°02.50´S, 34°03.00´S, 34°03.50´S and 34°04.00´S respectively. The respective depths at these positions were 47, 55, 75 and 89 m. The GPS units recorded position and time at one-minute intervals. Each contemporary trial was labelled as a, b, c, or d, prefaced by the trial-batch number.

The accuracy of the GPS unit was determined experimentally by analysing the time-series from a stationary GPS on three occasions. Most of the readings (95%) were within a distance of 60 m of the mean position.

The radio beacon was used to locate the drogue with a direction finder, and had a nominal detectable range of five miles. This distance constrained the time that the drogues could be left unattended without the risk of losing instruments. Deployment and retrieval was from a small craft launched from the Storms River mouth. On several occasions, equipment failure limited the number of drogues to fewer than four.

Independent position and time measurements taken at release and retrieval proved necessary because the GPS unit failed occasionally, leaving only a start and finish position, with no track information. In addition, depth and temperature-at-depth (10-m intervals) were recorded at release and retrieval. The depth of the thermocline was assumed to lie between successive temperature measurements that differed by more than 1°C.

In 1998, 24-h drogue trials were performed. For those trials, two drogues were released simultaneously on Middlebank (34°02.72´S, 023°52.51´E) within 100 m of each other, and then recovered the following day, approximately 24 h later, using the same recording procedure as before.

Wind speed and direction data were obtained on a monthly basis from a South African Weather Bureau automated weather station located at the Storms River mouth. The data were filtered (New Hampshire Lanczos filter) to remove land-breeze effect and tidal effects to leave synoptic winds. A Seamon Mini recorder (manufactured by Hugrun, Iceland), was used for sea surface temperature recording. The instrument was located 12 m deep, slightly west of the Storms River mouth at 34°01.37´S; 023°53.98´E, and recorded every minute, from which hourly averages were extracted. The phase and the amplitude of the tides were taken from the *South African Tide Tables*, published by the naval hydrographic office, Simonstown.

RESULTS

Longshore movements accounted for the majority of drogue displacements. Drogues moved in a westerly (Table II) or an easterly direction (Table III), usually with consistent velocity during a drift (Fig. 2). Drogues that were initially spaced 0.5 miles apart, moved with consistent direction during the course of the drift. Direction was also usually consistent among simultaneously released drogues. Exceptions to this pattern were found when current reversals or inertial paths were encountered, which moved the drogues in a circular motion with reduced or variable velocity (Trials 12, 13, 17, 30 and 33; Fig 3).

There was a common pattern of inshore drogues moving faster, but in a similar direction, than those deployed farther offshore, irrespective of the direction (east or west) of travel (Trials 8, 9, 10, 15, 20, 21 and 23). Trials 14 and 22 were exceptions to this pattern. In the first of these trials, the drogue farthest offshore moved faster. In the second, the central two drogues moved faster while the drift of the inshore drogue was greatly retarded. Those drogues that were released together for 24 h did not separate (tracks of simultaneously deployed 24-h drogues are available for Trials 30 and 31 only).

There was no obvious seasonal pattern in current direction, although drogues were not released during every month of the year, nor with sufficient repetition to draw any conclusions about seasonal trends. Drift was strong westward and eastward in summer and

Table III: Details of eastward displacements. Horizontal lines group drogues run on consecutive days

Drogue	Date	Dis-place-ment	Speed ($cm\ s^{-1}$)	Direction (degrees)	Δz (%)	SST (°C)	ΔSST (°C)	Thermocline depth (m)	Tidal phase (min.)	Tidal amplitude (m)	Wind direction of origin (degrees)	Wind velocity ($m\ s^{-1}$)
17A	15 Sep. 1996	1 676	10.3	56	-27	16.5	-0.2	N.A.	241	1.62	110	7
17B	15 Sep. 1996	3 306	19.8	66	-19	16.3	0.0	N.A.	249	1.62	110	7
18A	5 Nov. 1996	4 555	18.7	84	N.A.	17.5	0.1	>40 m	-171	0.73	350	1
18B	5 Nov. 1996	4 062	19.5	81	N.A.			>40 m	-128	0.73	350	1
18C	5 Nov. 1996	4 468	18.4	67	N.A.			>40 m	-157	0.73	350	1
18D	5 Nov. 1996	3 873	15.7	66	N.A.			>40 m	-140	0.73	350	1
23A	17 Jan. 1997	10 134	31.9	90	-40	22.1	-1.5	N.A.	-153	0.76	70	3
23B	17 Jan. 1997	8 953	30.0	89	-34			N.A.	-141	0.76	70	3
23C	17 Jan. 1997	5 392	19.7	82	-21			N.A.	-131	0.76	70	3
23D	17 Jan. 1997	3 971	15.6	94	-2			N.A.	-124	0.76	70	3
24A	13 Feb. 1998	1 475	9.2	88	4	9.0	0.9	Surface	266	1.51	240	4
24B	13 Feb. 1998	2 001	11.5	94	2			Surface	284	1.51	240	4
24C	13 Feb. 1998	2 030	11.7	93	4			Surface	297	1.51	240	4
24D	13 Feb. 1998	2 282	12.8	101	0			Surface	304	1.51	240	4
25A	14 Feb. 1998	4 454	15.8	95	21	9.9	0.5	0–10 m	178	1.47	0	0
25B	14 Feb. 1998	4 593	16.1	98	21			0–10 m	189	1.47	0	0
25C	14 Feb. 1998	5 008	17.4	88	-8			0–10 m	201	1.47	0	0
25D	14 Feb. 1998	5 106	17.8	87	-8			0–10 m	214	1.47	0	0
26A	15 Feb. 1998	3 176	13.5	101		10.4	0.0	N.A.	234	1.38	250	2
26B	15 Feb. 1998	3 075	13.0	99	8			N.A.	243	1.38	250	2
26C	15 Feb. 1998	2 626	11.5	90	0			N.A.	266	1.38	250	2
28A	12 Oct. 1998	15 985	17.9	91	-7	16.4	-0.9	>40 m	-313	0.67	260	3
28B	12 Oct. 1998	15 231	17.3	90	-52			>40 m	-303	0.67	260	3
29A	13 Oct. 1998	18 399	21.3	100	N.A.	15.5	-1.1	>40 m	305	0.55	250	8
31A	7 Dec. 1998	20 157	23.0	97	N.A.	12.6	-0.3	Surface	-55	1.24	240	5
32A	8 Dec. 1998	6 387	7.3	86	N.A.	12.8	0.1	0–10 m	-128	1.30	240	4
32B	8 Dec. 1998	6 338	7.2	83	N.A.			0–10 m	-122	1.30	240	4

Δz = change in depth of water along drogue track, SST = sea surface temperature, ΔSST = change in SST over 24 h

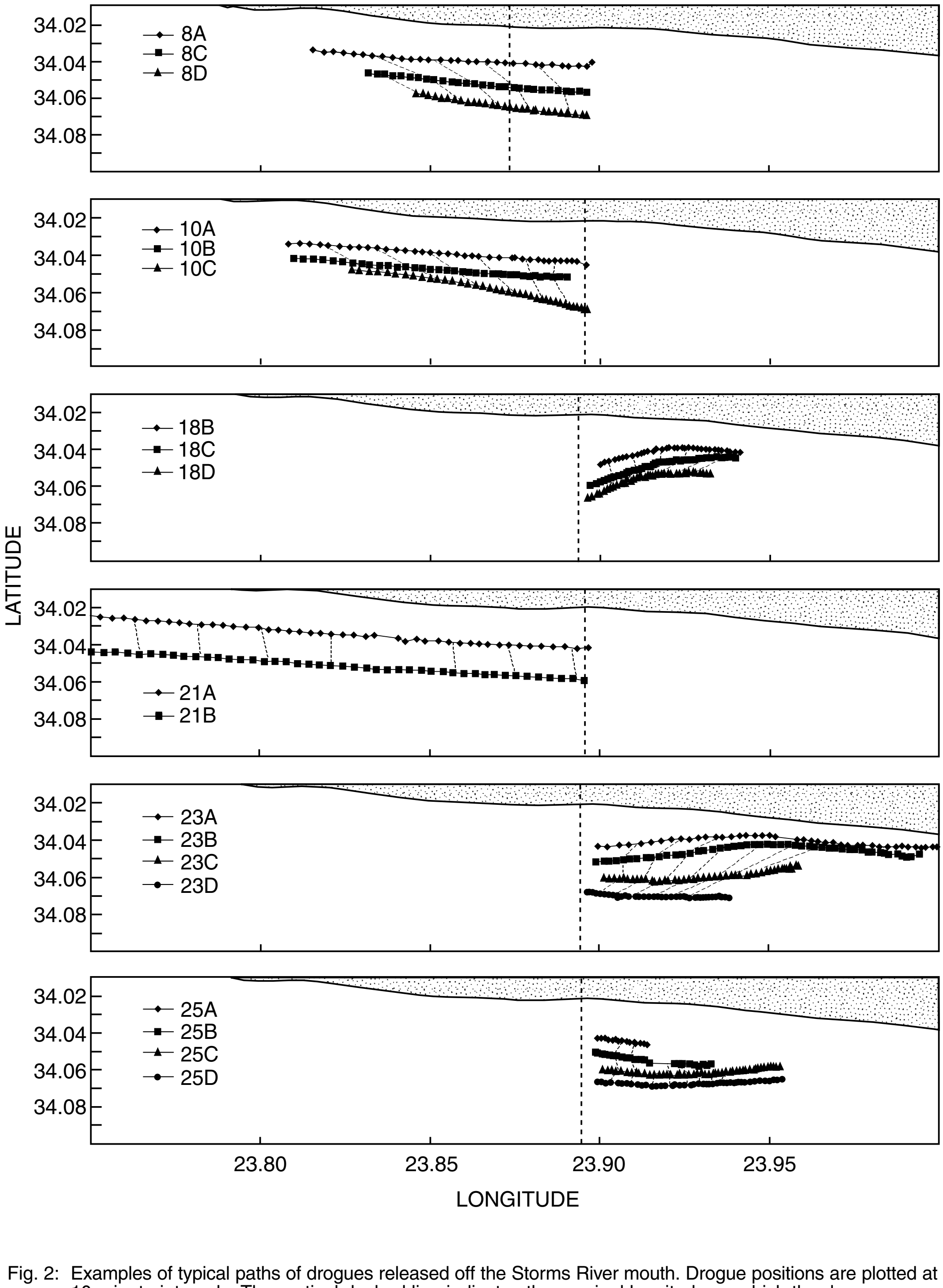

Fig. 2: Examples of typical paths of drogues released off the Storms River mouth. Drogue positions are plotted at 10-minute intervals. The vertical dashed line indicates the nominal longitude on which the drogues were released. Dotted lines join drogue positions at equal time, to show the relative acceleration of drogues

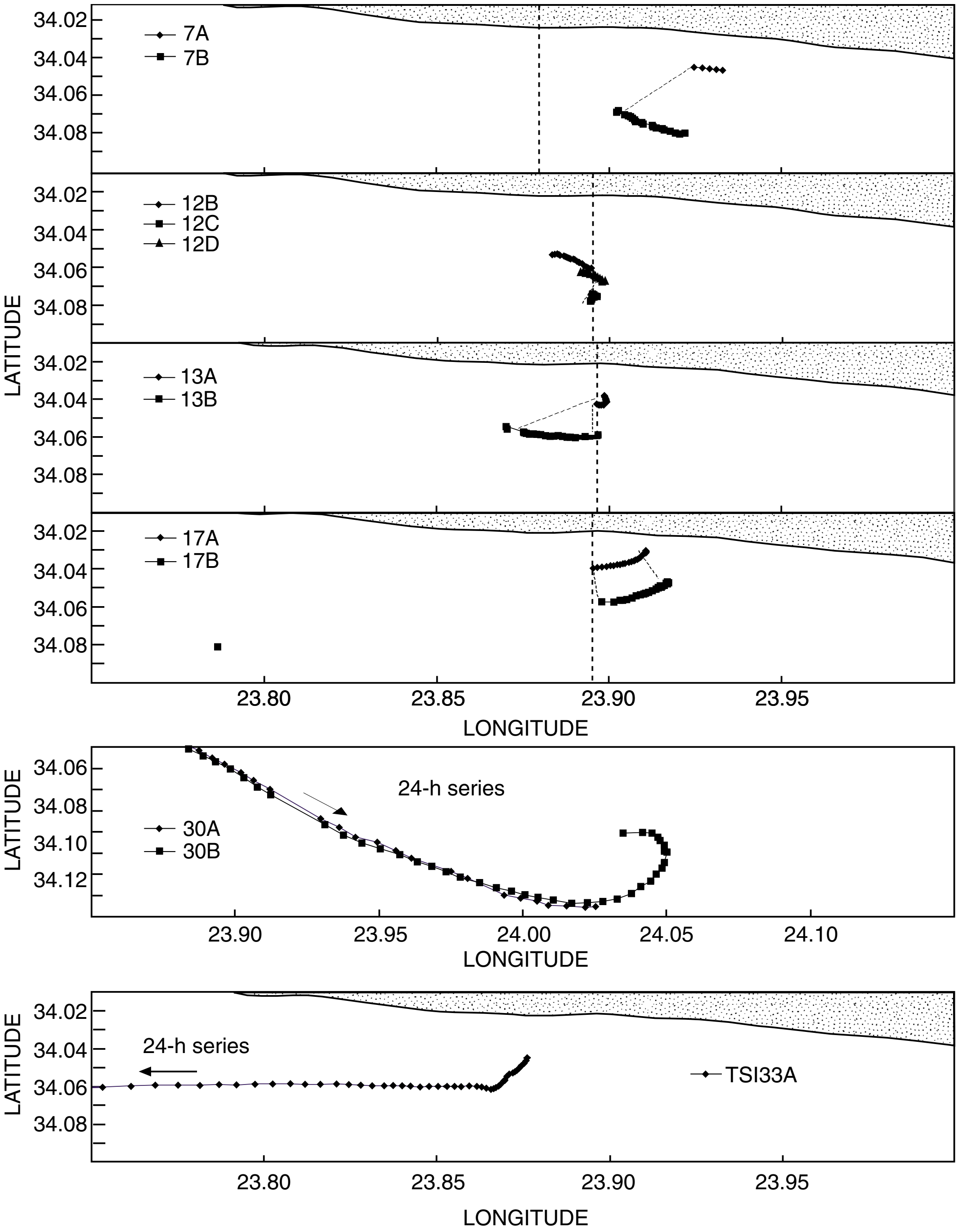

Fig. 3: Examples of typical paths of drogues released off the Storms River mouth. Drogue positions are plotted at 10-minute intervals, except for the two 24-h series (these are marked), for which drogue position was plotted every 30 minutes. The vertical dashed line indicates the nominal longitude on which the drogues were released. Dotted lines join drogue positions at equal time to show the relative acceleration of drogues

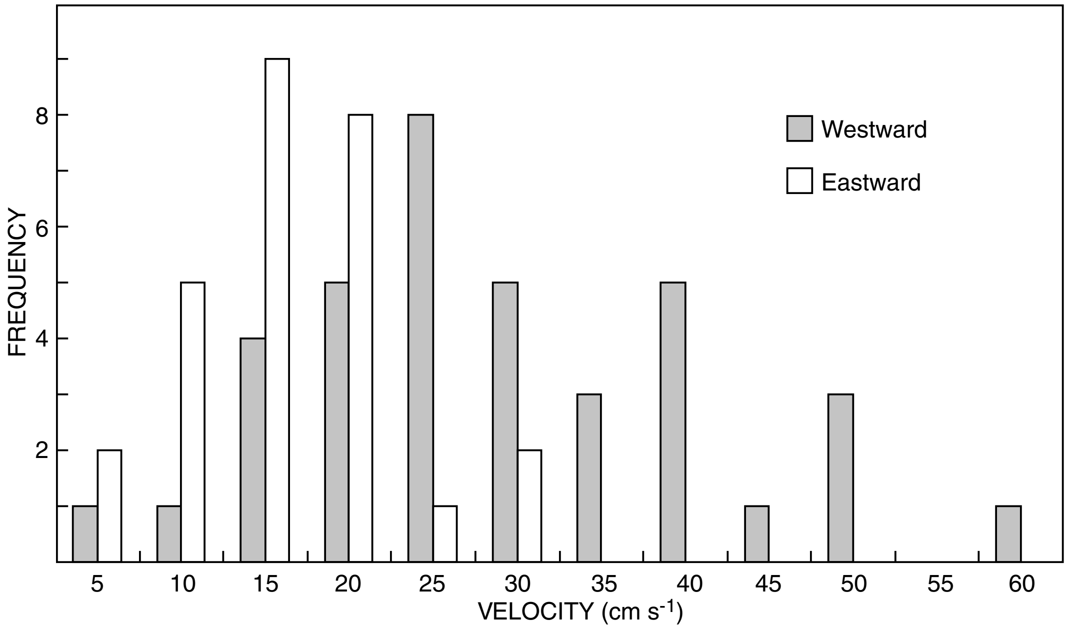

Fig. 4: Frequency distribution of drogue velocities off the Storms River mouth. Westward and eastward movements are shown separately

winter (Tables II and III). Average drogue velocities during the course of a drift ranged between 2 and 58 cm s^{-1}, with a modal velocity of 23.3 cm s^{-1}. The modal westward current velocity was greater than the modal eastward velocity (Fig. 4).

The error in velocity owing to GPS measurement error is very small and decreases with increasing displacement of the drogue. Given a 95% error in instantaneous GPS fixes of 60 m, the associated relative error in velocity calculated on a displacement of 1 000 m will be 6% and for 5 000 m it will be 1.2%. The median drogue displacement was 5 487 m, which implies that for most estimates the velocity error was <1.2%.

Wind and surface drift were poorly correlated. A similar number of drogues drifted upwind as downwind. Trials 8, 9, 19, 23 and 32 showed opposing current and wind directions (Tables II and III). Trials 32, 33 and 34, which occurred on consecutive days, showed a current switch that was timed perfectly with a wind switch. In theory, it is unlikely that the surface current can respond immediately to a change in wind direction, which suggests that the wind-current correlation during this trial may have been coincidental, or mediated through associated shelf wave phenomena (Schumann and Brink 1990).

In most cases, westward drift was combined with slight offshore movement as drogues moved to deeper water (Table II, Fig. 2), indicating that upwelling may have been in progress. Thermocline data were not available for the April 1996 drogue release, but it is evident that the westward drift was accompanied by a sustained decline in SST. On two other occasions, westward currents resulted in the lifting of the thermocline over a 24-h period (22–23 July 1996 and 9–10 December 1998). Both of these events also resulted in the surface temperature (SST) dropping sharply. On another occasion (20–22 January 1998) when the drogue did not move into deeper water, the thermocline lifted and then fell over 48 h, with no change in the SST.

During eastward movements, the drift was predominantly parallel to the shore or slightly onshore, usually resulting in movement to shallower water (Table III, Fig. 2). There was no marked pattern in SST change during eastward drifts, but there was evidence for downwelling in two cases. The thermocline deepened from 13 to 14 February 1998, and a thermocline developed in the well-mixed water column on 8 December 1998.

There was a high degree of correlation between the direction of drogues that were released on successive days. Unfortunately, no time-series was long enough to capture two successive current reversals. The highest number of consecutive days on which drogues were released was five. Current reversal may have occurred during Trial 12, after four days of strong westward currents, and during Trial 13 before two days of strong westward current (Fig. 3). Between Trial 31 and 33, the current switched from strong eastward to strong westward (Fig. 3).

The tidal influence appears to be negligible. Both the phase of the tide at release and maximum amplitude on the day of release varied greatly between trials that showed similar direction of movement (Table II, III).

DISCUSSION

Tilney *et al.* (1996) described three distinct current patterns in the TNP, based on stationary current-meter data and satellite images. During winter, barotropic current reversals have a frequency of 2–4 days and are strongest inshore. During summer, these reversals are present but not as strong. Instead, upwelling cycles dominate in spring and summer. For short periods of upwelling, Tilney *et al*. (1996) argued that surface water would be transported 30–40 km offshore, after which a relaxation of wind would bring a compensatory downwelling movement, resulting in small upwelling cells. During longer periods of upwelling, lasting 10 days, surface water could be transported 70–90 km offshore, and 200–250 km longshore. They mention that this last mechanism, which was deduced from satellite infra-red images, has yet to be tested.

This study deployed drogues for periods that were too short to test theories of large-scale upwelling circulation. The drogues did not show any clear seasonal pattern. In practice, it was difficult to distinguish between the winter model, of frequent barotropic current reversals, and the summer model, of upwelling/downwelling cycles from discrete drogue tracks. The general pattern was that west-moving surface water moved offshore and east-moving water moved onshore, but there were exceptions to this trend. These movements may correspond to upwelling and downwelling respectively, but the currents were not driven by wind.

The drogues tested the contention that winds could substantially modify the surface current pattern, and hence provide a transport mechanism that differed from the underlying water below a thermocline. Overall, it would appear that local winds do not influence the direction of surface water movement in TNP. Likewise, there was no apparent tidal influence on the movement of the drogues, a finding consistent with the current-meter study of Tilney *et al*. (1996).

Drogues were used by Boyd (1982) to calculate vertical shear and horizontal diffusion in upwelled water off the Cape Peninsula. Surface water moved more rapidly than the 10- and 20-m layers, which resulted in vertical shear that had the potential to disperse particles more extensively than horizontal diffusion alone. The extent of the latter was calculated from initial drogue separation rates, which averaged 8.1 m h^{-1} for surface water. Off Storms River mouth, the 24-h trials (drogues were released within 100 m of each other) showed no tendency to separate. This result suggests that the dominant scale of turbulence was much larger than the distance between the drogues to force separation. These trials occurred during high current velocities. Eddies of at least 5 km diameter were apparent during Trials 13 and 31. Some horizontal shear was evident from those trials in which inshore drogues travelled faster than offshore drogues.

In conclusion, it appears that the surface currents off the Storms River mouth are not driven by winds or tides, but are likely to follow the motion of coastal trapped waves as described by Tilney *et al*. (1996) for deeper water. Table II and III show that current direction remained consistent for periods of at least three or four days. The currents are predominantly longshore and have the capacity to transport planktonic organisms beyond the park boundaries (70 km E–W × 5.6 km N–S) within 48 h. A description of large-scale circulation patterns will require the use of satellite-tracked drogues.

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LITERATURE CITED

BOYD, A. J. 1982 — Small-scale measurements of vertical shear and rates of horizontal diffusion in the southern Benguela Current. *Fish. Bull. S. Afr.* **16**: 1–9.

BUXTON, C. D. 1993 — Life-history changes in exploited reef fishes on the east coast of South Africa. *Environ. Biol. Fishes* **36**: 47–63.

BUXTON, C. D. and M. J. SMALE 1989 — Abundance and distribution patterns of three temperate marine reef fish (Teleostei: Sparidae) in exploited and unexploited areas off the Southern Cape coast. *J. appl. Ecol*. **26**: 441–451.

GRIFFITHS, M. H. 1997 — Towards a management plan for the

South African linefishery: objectives and strategies. In *Management and Monitoring of the South African Marine Linefishery.* Penney, A. J., Griffiths, M. H. and C. G. Attwood. (Eds). *Occ. Rep. S. Afr. Network Coast. oceanic. Res.* **3**: 3–14.

NIILER, P. P., SYBRANDY, A. S., KENONG, B. I., POULAIN, P. M. and D. BITTERMAN 1995 — Measurements of the water-following capability of holey-sock and TRISTAR drifters. *Deep-Sea Res.* **42**(11/12): 1951–1964.

ROBERTS, M, and M. VAN DEN BERG (in press) — ADCP-measured currents along the Tsitsikamma coast, South Africa, and potential transport of squid paralarvae and ichtyoplankton. *S. Afr. J. mar. Sci.* **25**.

SCHUMANN, E. H. and K. H. BRINK 1990 — Coastal-trapped waves off the coast of South Africa: generation, propagation and current structures. *J. phys. Oceanogr*. **20**: 1206–1218.

TILNEY, R. L., NELSON, G., RADLOFF, S. E. and C. D. BUXTON 1996 — Ichthyoplankton distribution and dispersal in the Tsitsikamma National Park marine reseve, South Africa. *S. Afr. J. mar. Sci*. **17**: 1–14.

WARNER, R. R., SWEARER, S. E. and J. E. CASELLE 2000 — Larval accumulation and retention: implications for the design of marine reserves and essential fish habitat. *Bull. mar. Sci.* **66**: 821–830.

WOOD, A. 1998 — A contribution towards the taxonomy of the ichthyoplankton species community and understanding of its dynamics along the south east coast of South Africa. Ph.D. thesis, Rhodes University: 338 pp.