

# Horizontal and vertical distributions of larvae of Pacific bluefin tuna *Thunnus orientalis* in patches entrained in mesoscale eddies

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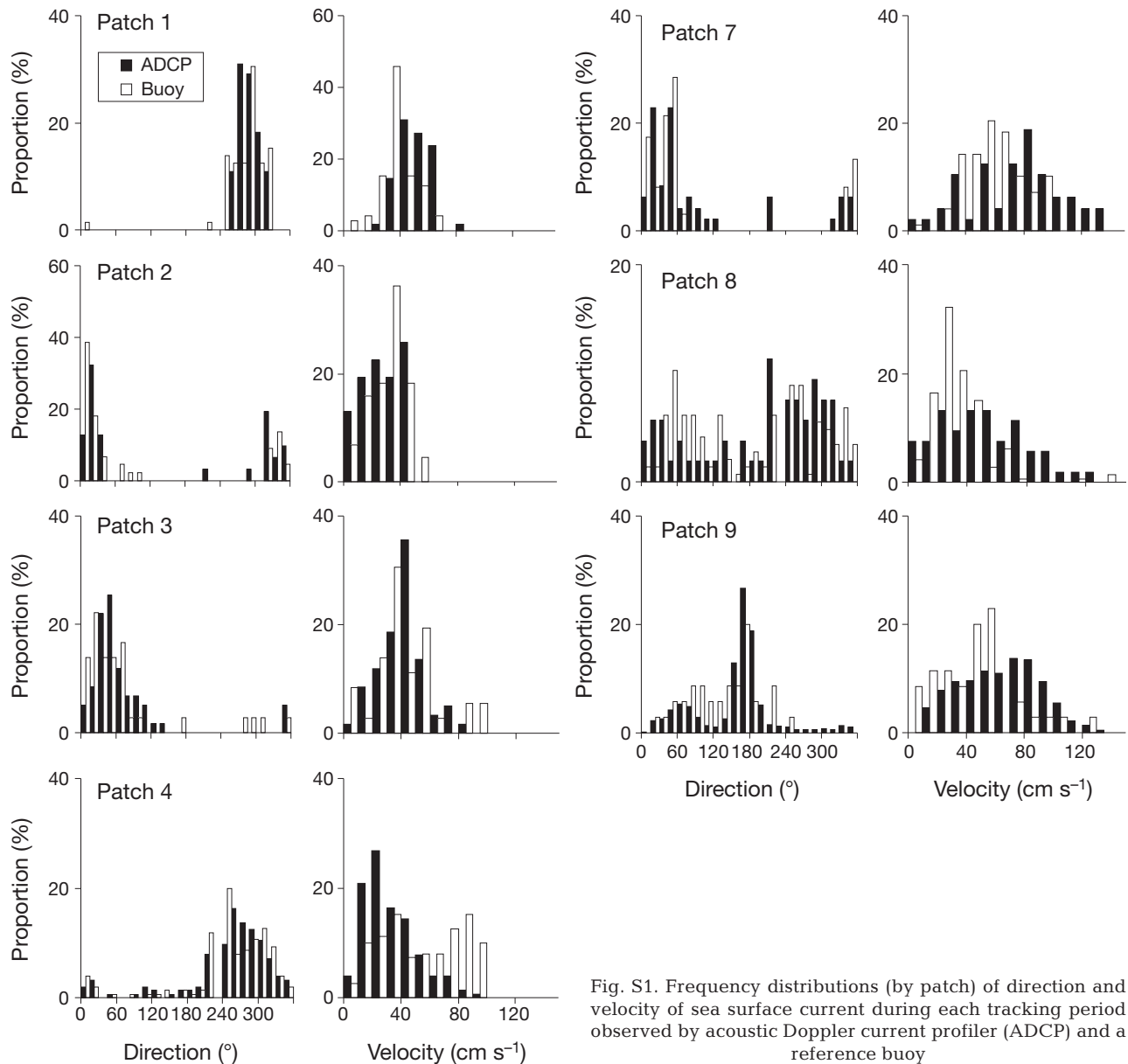


Fig. S1. Frequency distributions (by patch) of direction and velocity of sea surface current during each tracking period observed by acoustic Doppler current profiler (ADCP) and a reference buoy

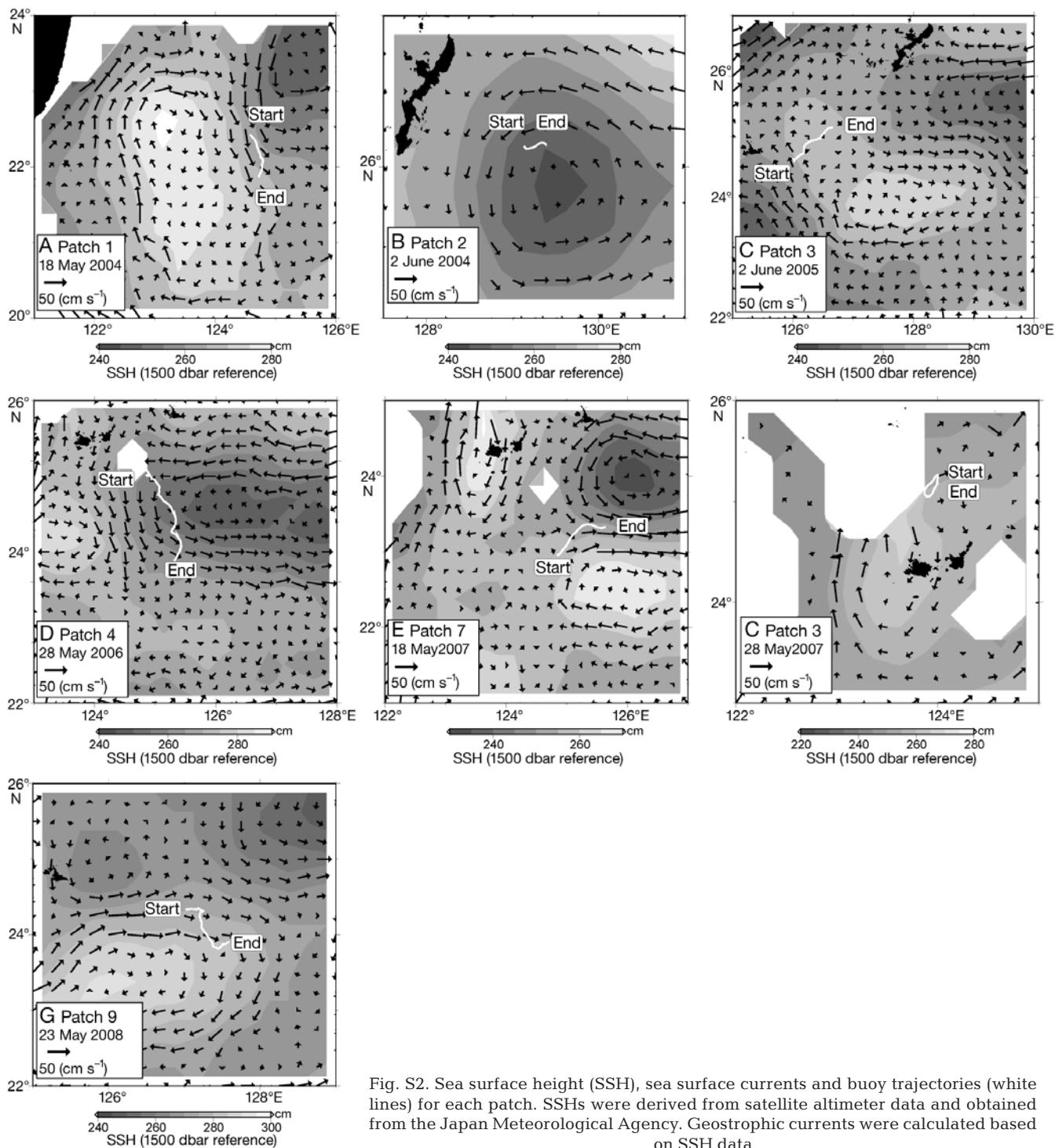


Fig. S2. Sea surface height (SSH), sea surface currents and buoy trajectories (white lines) for each patch. SSHs were derived from satellite altimeter data and obtained from the Japan Meteorological Agency. Geostrophic currents were calculated based on SSH data

Table S1. *Thunnus orientalis*. Summary of basic statistics arranged by day after hatch (DAH) on each Tracking day for surface tows: mean, maximum and coefficient of variation of larval density (ln + 1). NS: number of stations; zero: percentage of stations where no larvae were collected

Patch	Track	NS	DAH 4				DAH 5				DAH 6				DAH 7			
			Mean	Max	CV	Zero	Mean	Max	CV	Zero	Mean	Max	CV	Zero	Mean	Max	CV	Zero
1	0	21					6.9	9.3	2.51	52%	6.5	8.1	1.37	19%	6.4	8.0	1.15	0%
	1	7					4.8	6.0	1.18	43%	5.7	6.5	0.92	29%	5.6	6.5	0.94	0%
	2	7																
2	0	21					4.2	6.5	2.38	43%	5.8	7.6	1.41	10%	6.0	7.3	0.94	0%
	1	7									0.6	1.4	1.71	71%	3.2	4.6	1.50	43%
3	0	4					7.6	8.2	0.92	25%	8.3	9.2	1.11	25%	7.9	9.0	1.35	25%
	1	11					6.0	8.1	2.46	64%	5.8	7.5	1.77	45%	5.2	7.0	1.79	45%
	2	15									1.9	3.8	2.64	87%	3.1	4.8	1.81	53%
	3	4													2.3	3.5	1.70	25%
4	0	6	16.0	17.3	1.50	0%	14.2	15.4	1.46	0%	9.9	11.0	1.22	0%	5.7	7.2	1.82	33%
	1	6	11.2	12.4	1.21	33%	11.5	13.0	1.64	33%	10.1	11.7	1.96	50%	6.8	8.4	2.07	50%
	2	7	9.5	11.2	2.00	43%	10.6	11.4	0.93	14%	9.7	10.5	0.99	14%	7.8	8.8	1.01	14%
	3	7					6.1	7.7	1.73	29%	7.2	8.5	1.28	29%	6.9	7.4	0.71	29%
	4	7					1.6	2.9	1.78	71%	4.6	5.9	1.29	43%	5.4	6.4	1.04	43%
	5	7					3.3	5.1	2.51	71%	4.3	6.0	2.06	71%	3.6	5.0	1.49	0%
	6	7									1.9	3.6	2.36	71%	2.8	4.2	1.76	71%
	7	7					3.8	5.1	1.71	71%	4.7	6.0	1.71	71%	3.2	4.7	1.85	43%
7	0	4	6.5	7.2	1.16	50%	9.7	10.3	0.90	25%	9.6	10.7	1.27	25%	8.2	9.4	1.43	25%
	1	5	5.8	7.4	2.24	80%	7.7	9.0	1.53	0%	8.0	8.9	1.22	20%	8.2	9.2	1.21	20%
	2	5	4.5	5.5	1.28	20%	6.1	7.0	0.90	0%	6.8	7.6	0.90	0%				
8	0	3					1.8	2.3	0.90	33%	4.5	5.1	0.98	33%	5.1	5.7	0.94	0%
	1	5									0.4	1.3	2.24	80%	2.2	3.1	1.38	60%
	2	5																
9	0	1																
	1	6																
	2	6																
	3	4																
Patch	Track	NS	DAH 8				DAH 9				DAH 10				DAH 11			
			Mean	Max	CV	Zero	Mean	Max	CV	Zero	Mean	Max	CV	Zero	Mean	Max	CV	zero
1	0	21	5.5	7.1	1.07	0%	3.5	4.5	0.84	0%	1.5	3.1	1.41	29%	1.9	3.2	1.32	24%
	1	7	5.3	6.3	1.07	0%	4.0	4.8	0.93	0%	3.7	5.5	2.16	0%	4.7	6.6	2.54	0%
	2	7	0.5	1.1	1.43	29%	0.7	1.2	0.86	14%	1.8	3.0	1.16	0%	5.3	7.2	2.55	0%
2	0	21	5.2	6.6	1.10	0%	4.5	6.2	1.26	0%	4.1	6.0	1.58	0%	3.3	5.0	1.53	5%
	1	7	3.7	5.2	1.68	0%	3.5	5.0	1.61	0%	4.1	5.5	1.38	0%	4.4	5.6	1.15	0%
3	0	4	6.0	7.1	1.44	25%	3.0	4.2	1.58	25%	0.4	1.1	2.00	75%	0.0	0.0	2.00	75%
	1	11	4.3	6.0	1.81	45%	3.5	5.3	2.02	45%	2.2	3.6	1.76	64%	0.7	2.5	3.11	82%
	2	15	3.1	4.5	1.40	33%	2.6	3.9	1.21	27%	1.9	3.1	1.12	33%	0.3	1.3	1.93	47%
	3	4	2.4	3.5	1.32	0%	1.2	1.7	0.67	0%	0.8	1.2	0.78	25%	0.3	0.7	1.76	25%
4	0	6	2.7	4.0	1.59	67%	0.1	0.6	2.45	83%	0.0	0.1	2.45	83%	0.1	0.5	2.45	83%
	1	6	2.9	4.5	1.98	67%	0.3	1.2	2.15	67%	0.6	1.7	2.45	83%	0.0	0.2	2.45	83%
	2	7	4.3	5.2	0.94	14%	1.3	2.5	1.50	43%	0.6	1.2	1.36	57%	0.4	1.0	1.75	71%
	3	7	5.6	6.8	1.15	29%	2.8	4.2	1.47	29%	0.7	1.6	1.36	43%	0.4	0.8	1.29	57%
	4	7	4.5	5.3	0.98	43%	3.2	4.0	1.07	29%	1.9	3.0	1.24	29%	0.9	1.5	0.99	29%
	5	7	3.3	4.2	0.93	14%	3.2	4.2	1.19	14%	3.2	4.4	1.41	14%	2.9	4.2	1.51	14%
	6	7	1.8	3.4	2.08	57%	0.6	1.8	2.03	43%	0.9	2.3	2.21	57%	1.3	2.9	2.50	71%
	7	7	1.9	2.9	1.11	14%	1.2	1.6	0.60	14%	0.8	1.2	0.75	29%	1.4	2.2	1.10	29%
7	0	4	4.4	5.4	1.31	25%	0.3	0.8	1.52	50%								
	1	5	6.4	7.4	1.28	20%	2.9	4.0	1.44	40%								
	2	5	6.4	7.1	0.91	0%	5.0	5.8	0.83	0%	2.6	3.6	1.18	20%	0.3	0.8	1.69	40%
8	0	3	3.9	4.5	0.85	0%	2.4	3.3	1.42	0%	2.3	3.1	1.13	0%	2.4	3.3	1.30	0%
	1	5	2.2	3.2	1.38	20%	1.0	1.7	1.08	20%	1.1	2.2	1.60	20%	2.2	3.5	1.79	0%
	2	5																
9	0	1	0.7	0.7		0%	1.0	1.0		0%	1.2	1.2		0%	1.0	1.0		0%
	1	6	0.6	1.8		83%	1.1	2.5		83%	1.6	3.2		67%	1.3	2.7		67%
	2	6						0.1	0.2	50%	0.5	0.9		33%	1.3	2.1		17%
	3	4	0.4	1.0	75%	1.8	3.0	50%	2.4	3.6	50%							





Table S2 (continued)

Patch	Track	DAH 8			DAH 9			DAH 10			DAH 11						
		Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)	GOF	Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)	GOF	Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)		
4	0	Gau	0.74	286.80	0.00	0.38	Sph	7.88	255.30	6.66	Gau	3.41	15.30	1.00	0.24		
	1	Sph	0.14	212.05	0.07	0.82	Exp	64.45	2736.04	0.97	Sph	1.16	367.95	0.40	0.57		
	2	Exp	0.87	3.22	0.66	0.18*	Exp	1.60	14.78	0.38	Sph	1.24	11.59	1.00	0.35		
	3	Exp	2.48	24.13	1.00	0.19*	Exp	1.12	5.81	0.25	Exp	0.94	2.19	1.00	0.36		
	4	Sph	1.34	13.91	0.72	0.19*	Sph	1.31	13.63	0.76	Sph	1.32	13.98	1.00	0.18*		
	5	Sph	1143.91	28726.54	1.00	0.33	Sph	1.10	16.79	1.00	0.24*	Sph	1.19	17.88	1.00	0.21*	
	6	Exp	1.03	1.73	1.00	0.63	Gau	0.89	8.66	0.84	0.39	Gau	0.99	10.68	1.00	0.41	
7	7	Sph	1.14	12.89	1.00	0.41	Sph	0.98	12.93	1.00	0.33	Gau	1.42	17.15	0.00	0.58	
	0	Exp	0.09	8.00	0.60	0.92	Exp	3.34	8.00	0.47							
	1	Exp	10.96	101.82	1.00	0.29	Exp	1.72	8.75	1.00	0.32						
	2	Exp	1.37	1.64	1.00	0.41	Exp	1.43	6.51	1.00	0.41	Exp	1.71	2.44	1.00	0.50	
8	0	Exp	0.71	0.00	1.00	0.44	Sph	1.46	255.71	0.74	Sph	11.79	255.71	0.96	0.55		
	1	Gau	974.02	130.48	1.00	0.18	Gau	1.50	4.98	1.00	0.04	Sph	8.65	368.22	0.96	0.44	
	2																
9	0						Sph	3.65	368.10	0.58	Sph	2.34	368.10	0.94	0.68		
	1	Sph	7.31	368.10	0.94	0.41	Gau	1.39	4.80	0.29	Exp	61.22	1099.45	0.97	0.82		
	2						Exp	0.05	10.06	0.00	0.91	Gau	805.42	811.72	1.00	0.74	
Patch	Track	DAH 12			DAH 13			DAH 14			DAH 15						
		Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)	GOF	Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)	GOF	Model	Sill	Range (km)	Spatial dependence (1 - nugget/sill)		
		0	Sph	0.75	3.71	0.90	0.03*	Exp	53.05	1099.54	0.99	0.23	Gau	3301.73	261.76	1.00	5.40
		1	Gau	831.94	222.88	1.00	0.62	Gau	1846.95	223.96	1.00	0.63					
		2															
		0	Sph	1.04	6.03	0.91	0.09*	Gau	0.86	3.91	0.86	0.18*	Exp	48.81	1099.51	0.99	0.59
		1	Sph	8.14	306.85	0.96	0.54	Exp	90.73	1099.61	0.99	0.49	Gau	317.79	80.20	1.00	0.22
3	0																
	1																
	2																
4	0	Gau	3.40	15.30	1.00	0.24	Gau	3.40	15.30	1.00	0.24						
	1	Gau	1.87	1.08	0.28	1.30	Sph	0.65	4.98	1.00	0.64						
	3	Sph	0.79	7.19	1.00	0.33	Sph	0.75	8.71	1.00	0.30						
	4	Sph	20.46	763.31	0.98	0.28	Sph	1.75	26.68	0.91	0.12*	Gau	1.11	5.32	0.00	0.28	
	5	Sph	1.21	13.62	1.00	0.24*	Exp	28.19	2279.59	0.97	0.42	Sph	2.46	7.90	0.00	4.34	
	6	Gau	1.00	11.62	1.00	0.46	Gau	0.99	11.35	1.00	0.46	Gau	0.99	11.35	1.00	0.46	
	7	Exp	5.74	76.64	1.00	0.32	Exp	66.39	1024.30	1.00	0.30	Exp	764.54	12755.03	1.00	0.28	



Table S3. *Thunnus orientalis*. Effects of explanatory variables (day after hatch [DAH], Patch, Tracking day and towing method [tow]) on the indicators (range, sill, spatial dependence [1 – nugget/sill] and goodness-of-fit [GOF]) of spatial structure of the larval patches. Explanatory variables are treated as categorical variables

Patch	Indicator	Source	df	Adj SS	Adj MS	F	p
1 & 2	Sill	DAH	8	5.621	0.703	0.20	0.9761
		Patch	1	1.111	1.111	0.32	0.5946
		Error	5	17.215	3.443		
	Range	DAH	8	32.1	4.0	0.28	0.9449
		Patch	1	5.6	5.6	0.40	0.5568
		Error	5	71.2	14.2		
	Spatial dependence	DAH	8	0.054	0.007	0.45	0.8472
		Patch	1	0.014	0.014	0.96	0.3711
		Error	5	0.074	0.015		
	GOF	DAH	8	0.0136	0.0017	3.97	0.0729
		Patch	1	0.0038	0.0038	8.86	0.0309
		Error	5	0.0021	0.0004		
3	Sill	DAH	5	0.160	0.032	6.58	0.0759
		Tracking day	1	0.031	0.031	6.37	0.0858
		Error	3	0.064	0.021		
	Range	DAH	5	36.8	7.4	2.01	0.2998
		Tracking day	1	6.9	6.9	1.88	0.2635
		Error	3	11.0	3.7		
	Spatial dependence	DAH	5	0.068	0.014	2.38	0.2528
		Tracking day	1	0.006	0.006	1.00	0.3910
		Error	3	0.043	0.014		
	GOF	DAH	5	0.0037	0.0007	1.41	0.4132
		Tracking day	1	0.0182	0.0182	34.41	0.0099
		Error	3	0.0016	0.0005		
4	Sill	DAH	8	0.863	0.108	0.60	0.7510
		Tracking day	4	1.294	0.323	1.81	0.2457
		Error	6	1.072	0.179		
	Range	DAH	8	315.8	39.5	2.26	0.1686
		Tracking day	4	303.6	75.9	4.34	0.0548
		Error	6	105.0	17.5		
	Spatial dependence	DAH	8	0.039	0.005	0.65	0.7179
		Tracking day	4	0.121	0.030	4.04	0.0633
		Error	6	0.043	0.007		
	GOF	DAH	8	0.0102	0.0013	1.32	0.3775
		Tracking day	4	0.0047	0.0012	1.22	0.3935
		Error	6	0.0428	0.0071		
5 & 6	Sill	DAH	6	0.372	0.062	13.81	0.2031
		Tow	1	0.102	0.102	22.66	0.1318
		Error	1	0.004	0.004		
	Range	DAH	6	10.7	1.8	0.36	0.8520
		Tow	1	4.4	4.4	0.89	0.5184
		Error	1	4.9	4.9		
	Spatial dependence	DAH	6	0.034	0.006	0.17	0.9502
		Tow	1	0.047	0.047	1.38	0.4485
		Error	1	0.034	0.034		
	GOF	DAH	6	0.4213	0.0702	1.00	0.6437
		Tow	1	0.3816	0.3816	5.44	0.2578
		Error	1	0.0700	0.0700		



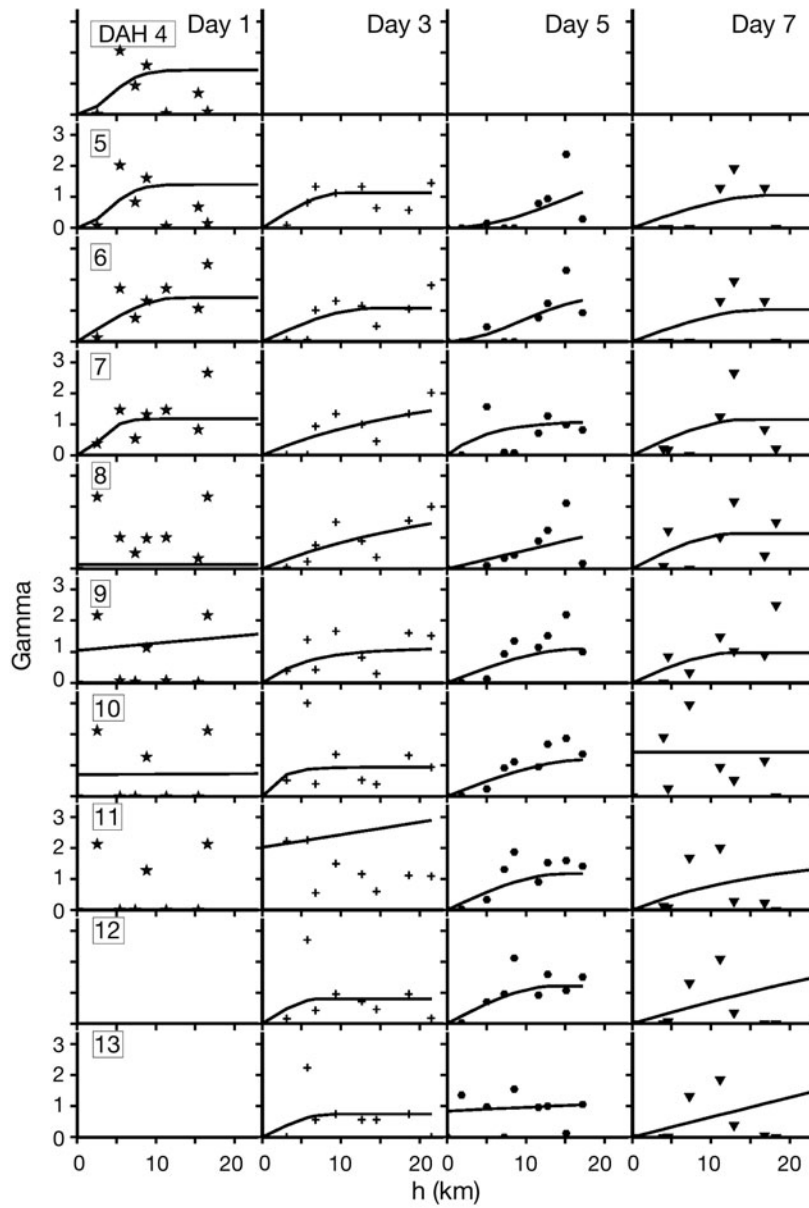


Fig. S3. Surface tows. Relative (to sample variance) experimental variograms from Tracking day 0 to 7 (\*: Tracking day 1; +: Tracking day 3; ●: Tracking day 5; ▼: Tracking day 7) and modeled variograms (—) for each day after hatch (DAH) of Patch 4.  $h$ : distance between stations (km). Lag =  $2.0 \pm 1.0$  km. Each fit used all experimental variograms (maximum distance distributed from 12 to 25 km)

Table S4. *Thunnus orientalis*. Summary of basic statistics and theoretical model arranged by day after hatch (DAH) and towing methods at 30 (surface tows) and 23 (oblique tows) stations in June 2006 including Patches 5 and 6. Zero: percentage of stations where no larvae were collected; Exp: exponential model; Gau: Gaussian model; spatial dependence: 1 – nugget/sill; GOF: goodness of fit; \*models used for statistical analysis

DAH	Larval density (ln+ 1)			Zero (%)	Model	Sill	Range (km)	Spatial GOF dependence	
	Mean	Max	CV						
<b>Surface tow</b>									
4	7.1	9.9	3.82	93	Exp	0.50	2735.6	0.95	2.00
5	6.3	9.4	4.08	80	Exp	0.89	2.8	1.00	0.66*
6	5.9	8.5	2.77	67	Exp	1.10	6.3	1.00	0.60*
7	5.6	7.9	2.40	67	Exp	1.11	5.2	1.00	0.43*
8	4.1	6.1	2.27	67	Exp	1.07	3.4	1.00	0.47*
9	1.6	3.9	2.60	73	Exp	1.05	3.7	1.00	1.08
10	0.2	1.3	2.84	87	Exp	0.80	2.3	1.00	0.91*
11	0.1	0.7	2.74	83	Gau	0.43	2.2	1.00	0.25*
12	0.0	0.4	4.88	93					
13	0.0	0.1	5.48	97					
14	0.0	0.0	5.48	97					
15				100					
16	0.0	0.6	5.48	97					
17	0.0	0.6	5.48	97					
18	0.0	0.3	5.48	97					
<b>Oblique tow</b>									
4				100					
5	5.9	8.5	3.27	78	Exp	0.95	44.6	1.00	0.34
6	5.3	7.6	2.81	78	Exp	0.85	6.2	0.97	0.25*
7	4.3	7.2	3.86	78	Exp	0.07	2.1	0.83	0.95
8	2.4	5.2	3.60	78	Exp	0.13	2.1	0.83	0.75
9	0.5	2.3	2.78	78	Gau	0.66	8.0	0.60	0.20*
10	0.1	0.8	3.34	91	Exp	0.92	90.8	1.00	0.13
11	0.0	0.3	3.23	87					
12	0.0	0.5	4.80	96	Exp	1.06	197.9	1.00	0.31
13	0.1	0.4	2.39	83					
14	0.0	0.3	2.40	83					
15	0.0	0.3	2.99	83					
16	0.0	0.1	2.80	87					
17	0.0	0.1	4.80	96					
18	0.0	0.1	4.80	96					