Working Paper #12
VMS

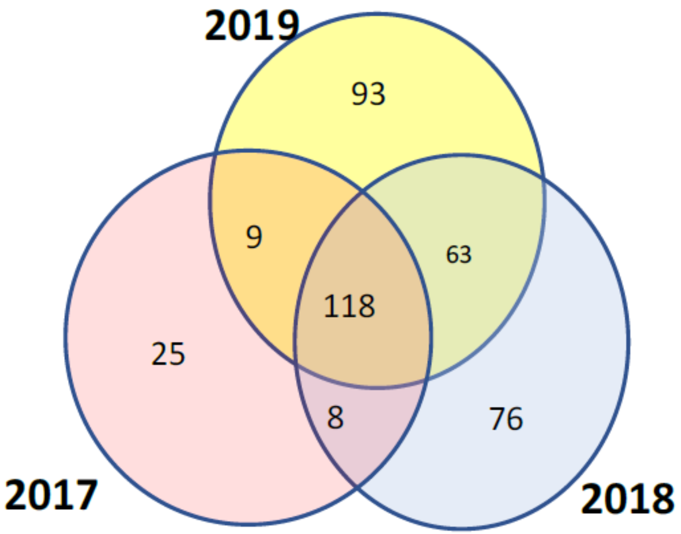
VMS Data

- 2017-2019 only
- Filtered by speed: [2.6 - 3.3 knots]
- Inshore “Loligo” sites excluded
- Locations binned by 3 minute sqr~6.99 nm^2 at 35 deg N Lat= “Cell”
- Net width linked to Permit Type
  - Allowed estimate of area swept in each cell
  - Ping frequency = 1/hour.
  - Area swept/Permit/Cell/Trip = net width x sum of hours at fishing speeds

Total Swept Area by Year

	2017	**2018**	**2019**	**Total**
Total Area Swept (nm^2)	402.2	545.4	940.6	1888.2
Number cells	160	265	283	392
Total Area of cells with fishing activity (nm^2)	1118.4	1852.35	1978.17	2740.08
Ave Area Swept (nm^2)/cell	0.360	0.294	0.475	

Unique Cells fished by Year



- Key fishing sites are used by multiple permits.
- 54 sites were visited by 10 or more different permits
- 75% of total fishing activity took place in these 54 cells

Table 2. Overlap of fishing effort and total swept area, 2017-2019.

# cells	# permits observed fishing in cell	Total Number of Pings	Total Area Swept (nm^2)
163	1	310	28.11
66	2	399	43.36
26	3	214	22.42
16	4	239	24.09
14	5	348	38.65
16	6	544	56.87
10	7	322	32.61
13	8	792	74.55
14	9	1683	134.14
8	10	1381	153.21
8	11	1882	210.16
4	12	648	77.97
9	13	1427	165.58
7	14	2789	342.21
2	15	334	32.41
5	16	1266	93.94
3	17	815	66.18
1	18	289	20.01
3	19	1718	124.66
3	20	1487	106.53
1	21	469	40.51

What are the implications of effort concentration for fishing mortality?

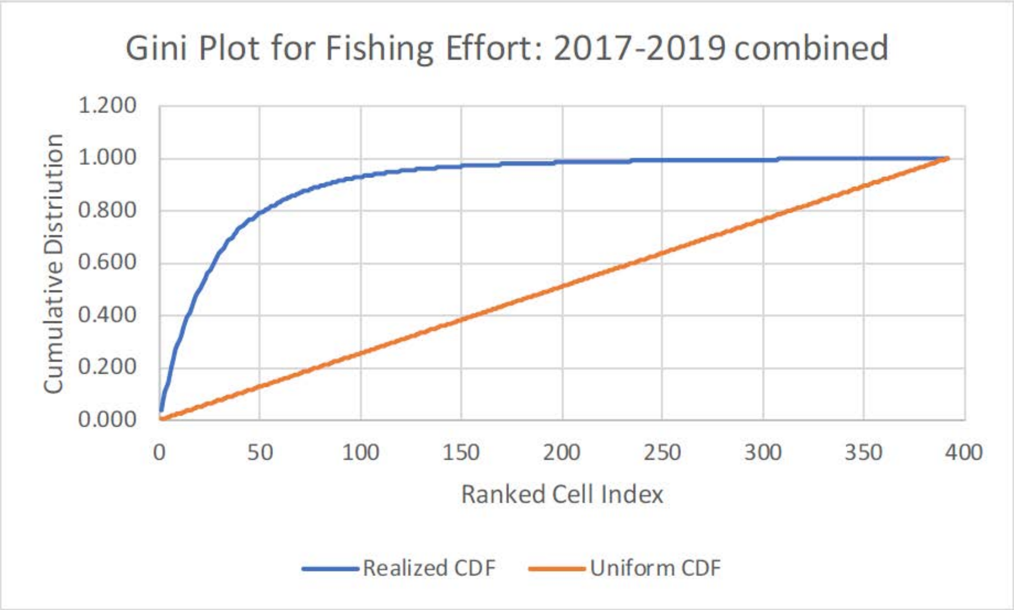


Figure 2. Gini plot of VMS fishing effort for 2017 to 2019 combined. X-axis is index of cells in which fishing occurred, sorted from highest to lowest frequency. Y-axis is cumulative distribution function for observed and hypothetical uniform distribution. Gini Index for pooled 2017-2019 = 0.822. Individual years are higher!

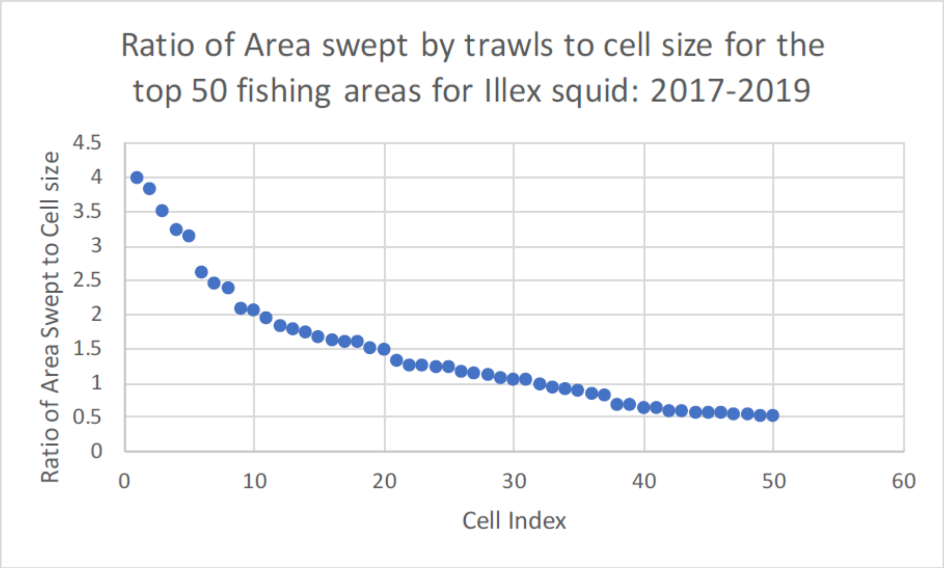


Figure 3. Concentration profile: ratio of total area swept to cell size for the top 50 fishing areas for Illex squid, 2017-2019.

What are the implications of these patterns for fishing mortality rates?

The total swept area (TS)after **n** tows of varying size **ai** is

$$TS = \sum_{i=1}^{n} a_i \qquad (4)$$

The fraction of the population remaining after it has been exploited **n** times by a gear with efficiency **q** and a swept area per tow of **ai**.

$$e^{\left(-\frac{q\,TS}{A}\right)} \qquad (5)$$

Thus the fraction of the population remaining after an area swept of **TS** or a ratio of **TS/A** times.

In the most heavily fished cells, the implied reductions in abundance are equivalent to the implied reductions in catch per unit effort. The "implied" depletion, given the VMS data is depicted in Figure 4.

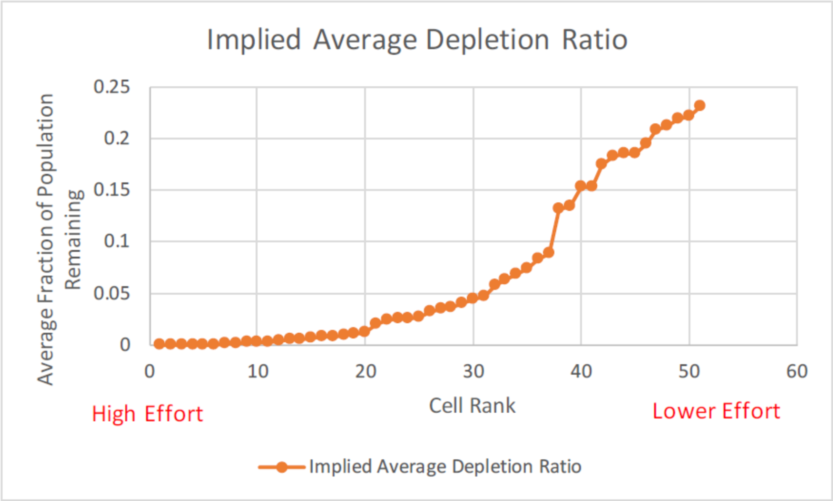


Figure 4. Implied depletion of population based on the ratio of average total area swept by trawls for the 50 most heavily fished cells. A gear efficiency of 100% is assumed for this plot.

Virtual Area Fished.

Let γ represent the ratio of CPUE that induces a movement of a vessel into a new area. Conceptually, this might be related to an economic incentive related to the profitability and an assumed profitability of the next tow. Conversations with fishermen suggested that this may not be a hard and fast rule since many different factors can affect the decision to move to another fishing area. Let $CPUE_o$ represent the initial CPUE and $CPUE_t$ represent the CPUE after time t has elapsed. The ratio of $CPUE_t/CPUE_o=\gamma$ such that a new area is fished when the ratio falls below γ. For economy this ratio can be called a "move along" criterion.

Using the swept area notation from Eq. 5 the CPUE ratio can be written as

$$\gamma = \frac{CPUE_t}{CPUE_o} = e^{\left(-q\frac{TS}{A}\right)} \quad (6)$$

Where q is the gear efficiency, TS is the total area swept in time step **t** and **A** is the area of the cell. Equation 1 can be rearranged to solve for A such that

$$A_V = \frac{-q\,TS}{\ln(\gamma)} \quad (7)$$

Table 3. Virtual area swept (km2) as a function of assumed gear efficiency and threshold for decline in CPUE with a trip for movement to a new fishing area. Combined years 2017-2019.

	Effective Area	Assumed Gear Efficiency									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Depletion Ratio Threshold	0.95	4575.5	9151.1	13726.6	18302.1	22877.7	27453.2	32028.7	36604.3	41179.8	45755.3
	0.85	1444.1	2888.2	4332.3	5776.4	7220.5	8664.6	10108.7	11552.8	12996.9	14441.0
	0.75	815.8	1631.6	2447.4	3263.2	4079.1	4894.9	5710.7	6526.5	7342.3	8158.1
	0.65	544.8	1089.6	1634.4	2179.2	2724.0	3268.9	3813.7	4358.5	4903.3	5448.1
	0.55	392.6	785.1	1177.7	1570.3	1962.9	2355.4	2748.0	3140.6	3533.2	3925.7
	0.45	293.9	587.8	881.7	1175.7	1469.6	1763.5	2057.4	2351.3	2645.2	2939.2
	0.35	223.6	447.1	670.7	894.2	1117.8	1341.3	1564.9	1788.4	2012.0	2235.6
	0.25	169.3	338.6	507.9	677.2	846.5	1015.8	1185.1	1354.4	1523.7	1693.0
	0.15	123.7	247.4	371.1	494.8	618.6	742.3	866.0	989.7	1113.4	1237.1

- Wright et al report 12,993 to 15,313 km^2 area fished
- This implies q between 0.3 and 1
- This implies γ (depletion ratio threshold) of ~0.85 to 0.95

Area Weighted Average F

The concept of virtual area fished can now be expanded to compute an area weighted fishing mortality rate. (Table 4). For each cell it is possible to compute the virtual area swept from Eq. 7. When the virtual area fished exceeds the actual cell size the magnitude of the fishing mortality in a given cell **i** is constrained by the defined threshold parameter γ. This can be expressed as

$$F_i = \min\left(-\ln(\gamma),\, q\, TS_i/A\right) \qquad (8)$$

The area weighted average F (**F**) over the entire set of cells fished in a given year can now be estimated as

$$F_{ave} = \frac{\sum_i^n F_i A_{Vi}}{\sum_i^n A_{Vi}} \qquad (9)$$

Note that F_ave is restricted to the areas where fishing is occurring or assumed to occur based on virtual area

Table 4. Spatially weighted F over all fishing areas as a function of gear efficiency and threshold for decline in CPUE within a trip for movement to a new fishing area. 2017-2019 combined.

	Spatially weighted average F	Assumed Gear Efficiency									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Depletion Ratio Threshold	0.95	0.0436	0.0468	0.0479	0.0486	0.0491	0.0494	0.0496	0.0498	0.0500	0.0501
	0.85	0.1066	0.1280	0.1370	0.1420	0.1455	0.1477	0.1493	0.1505	0.1514	0.1522
	0.75	0.1388	0.1968	0.2198	0.2312	0.2404	0.2465	0.2511	0.2549	0.2580	0.2603
	0.65	0.1511	0.2469	0.2949	0.3211	0.3359	0.3465	0.3560	0.3637	0.3693	0.3741
	0.55	0.1511	0.2818	0.3572	0.4042	0.4339	0.4534	0.4670	0.4776	0.4878	0.4967
	0.45	0.1511	0.3024	0.4053	0.4769	0.5278	0.5607	0.5871	0.6056	0.6197	0.6310
	0.35	0.1511	0.3024	0.4442	0.5379	0.6110	0.6683	0.7094	0.7410	0.7676	0.7880
	0.25	0.1511	0.3024	0.4540	0.5911	0.6860	0.7659	0.8321	0.8868	0.9287	0.9614
	0.15	0.1511	0.3024	0.4540	0.6059	0.7531	0.8652	0.9535	1.0344	1.1036	1.1643
	0.1	0.1511	0.3024	0.4540	0.6059	0.7579	0.9063	1.0218	1.1144	1.2007	1.2765

Ratio of Max to Min weighted F is 1.2765/0.0436 =29.3

OK, we have a range of potential fishing mortality rates in the areas fished. So what? We still don't have a range on the fishing mortality rate on the <u>entire</u> population.

- This depends on the rate of fishing mortality in the area fished

AND

- The density of squid in the fished and unfished areas

AND

- The ratio of habitat area fished to unfished.

Let **A** represent the total habitat area of Illex and $\mathbf{A_f}$ and $\mathbf{A_u}$ denote the areas were fishing does and does not occur, respectively. Thus

$$A = A_f + A_u \quad (8)$$

Further, let $\mathbf{D_f}$ and $\mathbf{D_u}$ represent the densities of Illex in the fished and unfished areas, respectively. Density can be expressed in either numbers or weight per unit area without loss of generality as long as average weights per individual are the same in each habitat area. The total population size **P** is thus defined as

$$P = A_f D_f + A_u D_u \qquad (9)$$

Beverton and Holt defined effective fishing mortality as the product of the fishing mortality times catch per unit effort summed over all spatial units, divided the sum of catch per unit effort over all spatial units. This is equivalent to a biomass weighted **F**. If we let $\mathbf{F_f}$ and $\mathbf{F_u}$ represent the fishing mortality rates in the fished and unfished areas, then the effective **F**, defined as $\mathbf{F_{eff}}$ is

$$F_{eff} = \frac{F_f A_f D_f + F_u A_u D_u}{A_f D_f + A_u D_u} \qquad (10)$$

Simplifying Eq 10

Equation 10 can be simplified by letting $\mathbf{D_u=\phi\ D_f}$, $\mathbf{A_f=\theta\ A}$, $\mathbf{A_u=(1\text{-}\theta)A}$ and noting that $\mathbf{F_u}=0$ by definition. Substituting these expressions into Eq 10 gives

$$F_{eff} = \frac{F_f \theta A\, D_f + 0\,(1-\theta) A \phi D_f}{\theta A D_f + (1-\theta) A \phi D_f} \qquad (11)$$

Canceling out the relevant symbols leads to

$$F_{eff} = \frac{F_f \theta}{\theta + (1-\theta)\phi} \qquad (12)$$

Table 5. Estimated fishing mortality on the entire population within the US resource area. Estimates based on the highest spatially weighted F in Table 4 = 1.2765.

Ratio of Area Fished to Total Habitat (theta)	Ratio of Density in Unfished Area to Density in Fished Area (phi)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
0.01	0.117	0.061	0.042	0.031	0.025	0.021	0.018	0.016	0.014	0.013
0.03	0.302	0.171	0.119	0.092	0.074	0.063	0.054	0.048	0.042	0.040
0.05	0.440	0.266	0.191	0.148	0.122	0.103	0.089	0.079	0.071	0.067
0.07	0.548	0.349	0.256	0.202	0.167	0.142	0.124	0.110	0.099	0.094
0.09	0.635	0.422	0.316	0.253	0.211	0.181	0.158	0.140	0.126	0.120
0.11	0.706	0.488	0.372	0.301	0.253	0.218	0.192	0.171	0.154	0.147
0.14	0.791	0.573	0.449	0.369	0.314	0.272	0.241	0.216	0.196	0.187
0.15	0.815	0.598	0.473	0.391	0.333	0.290	0.257	0.231	0.209	0.200
0.16	0.837	0.623	0.496	0.412	0.352	0.308	0.273	0.245	0.223	0.213
0.17	0.858	0.646	0.518	0.432	0.371	0.325	0.289	0.260	0.237	0.226
0.18	0.877	0.668	0.539	0.452	0.389	0.342	0.305	0.275	0.250	0.240
0.2	0.912	0.709	0.580	0.491	0.426	0.375	0.336	0.304	0.278	0.266

Range in Table 3 of Wright et al. (rows 0.01–0.07)