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Development of indices of performance for the Newfoundland and Labrador snow crab (*Chionoecetes opilio*) fishery using data from a vessel monitoring system

Élaboration des indices de rendement de la pêche du crabe des neiges (*Chionoecetes opilio*) de Terre-Neuve et Labrador à l'aide des données d'un système de surveillance des navires

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ABSTRACT

This study investigates the potential for using data from a vessel monitoring system (VMS) to create indices of commercial fishery performance that may be used in monitoring snow crab resource status. Fishing hours were screened from hourly positional signals to create an index of fishing effort (hours fished) for comparison with that derived from logbooks (number of trap hauls). Similarly, VMS-based fishing efficiency and catch per unit of effort (CPUE) indices were developed for comparison with CPUE derived from logbooks. Analysis of these indices showed that VMS-based fishing effort and CPUE indices can be developed to provide reliable alternatives to logbook indices. The VMS-based indices have advantages of being more objective, accurate, complete, and available in real time than logbook-based indices. VMS data offer other potential applications for snow crab assessment and management. Our approach and methods may be readily applicable to other commercial fishery resources worldwide that are monitored using vessel monitoring systems.

RÉSUMÉ

Cette étude examine les avantages d’utiliser les données d’un système de surveillance des navires (SSN) pour mesurer les indices de rendement de la pêche commerciale qui peuvent être utilisés dans la surveillance de l’état des ressources du crabe des neiges. Le nombre d’heures de pêche a été présélectionné à partir des signaux de position transmis toutes les heures, afin de créer un indice d’effort de pêche (nombre d’heures de pêche) aux fins de comparaison au nombre d’heures consigné dans le journal de bord (nombre de casiers levés). Dans le même ordre d’idée, les indices d’efficacité de pêche et de capture par unité d'effort (CPUE) établis en fonction du SSN ont été élaborés aux fins de comparaison aux CPUE issues du journal de bord. L’analyse de ces indices a démontré que les indices d’effort de pêche et de CPUE établis en fonction du SSN peuvent être élaborés pour fournir des solutions de rechange fiables aux indices du journal de bord. Les indices établis en fonction du SSN ont l’avantage d’être plus objectifs, plus exacts, plus complets et plus accessibles en temps réel que les indices établis en fonction du journal de bord. Les données du SSN offrent d’autres possibilités d’application pour l’évaluation et la gestion du crabe des neiges. Notre approche et nos méthodes peuvent être aisément applicables à d’autres ressources mondiales de pêche commerciale qui sont surveillées à l’aide de systèmes de surveillance des navires.

INTRODUCTION

The snow crab (*Chionoecetes opilio*) fishery in Atlantic Canada represents the world's largest crab fishery; it accounted for almost 90% of world landings in 2004, with over half of these landings coming from Newfoundland and Labrador (NL) (FRCC 2005). In 2007, the NL snow crab fishery landed 50,000 t, valued at $177 million (DFO 2008 unpublished). The NL snow crab fishery is managed by total allowable catch (TAC) and seasonal limitations. TACs are partitioned as individual quotas (IQs) among fishing enterprises. Each fishing enterprise is allocated an IQ to be harvested within a specific crab management areas (CMA, Fig. 1), toward achieving a broad spatial distribution of fishing effort. These CMAs have no biological relevance, and the resource status is assessed annually (Dawe et al. 2006) by larger units based on NAFO (Northwest Atlantic Fisheries Organization) Divisions (Fig. 2).

Fishery performance data from vessel logbooks are used in assessments, including fishing effort expenditure and catch per unit effort (CPUE) indices. CPUE is used as an index of exploitable biomass for comparison with survey-based biomass indices. There are concerns about the reliability of fishery data from vessel logbooks because they are incomplete and prone to error. Errors include missing or inaccurate positional, effort expenditure, catch, or temporal information. Data from fishery observers are insufficient to validate logbook indices because of low and inconsistent coverage. The target of observer coverage on 10% of commercial trips is rarely achieved and management and enforcement considerations can influence spatial or temporal coverage. Therefore, observer data is not always spatially or temporally representative of the fishery.

A vessel monitoring system (VMS) was implemented in offshore snow crab fleets in 2004 to ensure compliance with fishing area (CMA) regulations. To date, VMS has been primarily used for enforcement purposes and has not been explored with respect to its potential to provide data useful in developing fishery performance indices. VMS spatial information has been used to study the effects of fishing on aggregations of Alaska Pollock (*Theragra chalcogramma*) (Barbeaux et al. 2005) and to measure trawling intensity upon various substrate types in the Irish Sea (Mills et al. 2004).

In this paper we investigate the utility of using VMS to develop indices of fishing effort, CPUE, and fishing efficiency, for assessment purposes in the NL snow crab fishery. We compare VMS-based effort and CPUE indices to conventional indices from vessel logbooks and evaluate the relative benefits and deficiencies of indices developed from these two sources.

DATA AND METHODS

We limited our comparative study to CMAs within NAFO Div. 2J3KLNOPs (Fig. 1-2), because of logbook data limitations associated with Div. 4R (Dawe et al. 2006). The requirement to carry operable VMS while fishing is applicable only to offshore regions, so we limited our analysis to the offshore CMAs within these NAFO Divisions.

The VMS dataset consisted of hourly positional signals from Newfounland and Labrador fishing vessels from 2004 to 2007. Signals were relayed through satellite systems and stored at the Department of Fisheries and Oceans (DFO) Northwest Atlantic Fisheries Centre in St. John's, NL. We isolated snow crab trips by matching VMS data with the Dockside Monitoring Program (DMP) landings information for individual trips, based on vessel registration number (VRN), year, month, and day fished. Some VMS units (black boxes) provided speed as a variable, but the majority did not. We derived speed (knots) by calculating distance (nautical miles) and time (hours) between successive signals from a given vessel. 'Fishing signals' were accepted as those occurring within offshore CMA boundaries (Fig. 1), at 0.1–3.0 knot speeds. Based on personal experience, we assumed the majority of vessels in this fishery to normally steam at speeds greater than 3.0 knots. The snow crab fishery is prosecuted by deploying and retrieving 'fleets' or long-lines of baited traps (Dawe et al. 2006). The process of setting and hauling gear in this fashion necessitates a vessel to operate at slow speeds. Therefore, we accepted speeds of 0.1-3.0 knots on the fishing grounds as reflecting fishing activity. Signals with speeds of <0.1 knots were considered to represent inactivity by a vessel and were not interpreted as fishing signals.

Total hours of fishing activity was used as the VMS-based index of fishing effort and compared with total number of trap hauls, the effort index from logbook data. This comparison was made for weekly totals of trap hauls and fishing hours, by division from 2004 to 2007, using simple linear regression. The analysis was conducted for all trips from each index and further refined to trips that were common to both indices. To maintain independence from the logbook index, the landed catch data from DMP was used with VMS-based effort data to calculate a VMS-based CPUE index (kg/fishing hour). This source of landings data is considered to be the most complete and accurate because regulations require that all commercial fishing trips are monitored and total landings determined at dockside. The VMS-based CPUE index was compared with catch per trap haul, the CPUE index from logbook data (Dawe et al 2006). Cross-comparison of indices for common trips was carried out using both seasonal and weekly values from 2004 to 2007. The natural logarithm of each index was calculated and compared to control for scaling differences across the two indices. Weeks with less than 800 trap hauls or 20 fishing hours were omitted from the comparative analyses to control for small sample size effects. Seasonal trends in CPUE, based on weekly values (starting April 1) were compared between data sources using simple linear regression.

An index of fishing efficiency was derived as the number of pot hauls per hour (PPH) by isolating trips common to logbooks and VMS. For any given trip, the number of trap (pot) hauls from logbooks represented the numerator, while the number of fishing signals from VMS represented the denominator in the equation. Fishing efficiency was compared among division-specific fishing fleets. The index of efficiency was also subsequently compared, by fishing fleet and year, with logbook CPUE, using simple linear regression to determine the relationship between catch rates and the rates at which gear is deployed and retrieved in the fishery.

RESULTS

The degree of spatial overlap between VMS hourly effort and logbook sets was high in all divisions (Fig. 2). Distribution patterns were similar with VMS effort (fishing hours) being denser than logbook effort (sets), as a single set corresponded to multiple fishing hours (Table 1-2). When considering common trips captured by VMS and logbook datasets (Table 2), an average set represented 9.8 hours, but varied among divisions. Likewise, an average set consisted of 298 trap hauls with high variability across divisions. The logbook distribution tended to have more erroneous positions in deep water, not representing snow crab habitat, that were not evident in the VMS distribution. For example, set positions off the southwest slope of the Grand Bank in Div. 3O and east of the Hamilton Bank slope in Div. 2J likely do not accurately reflect fishing activity.

The relationship between number of trap hauls and number of fishing hours was generally strong in all divisions. Each division showed a positive, linear relationship between the two measures of effort, with r^2 ranging from 0.56 in Div. 3NO to 0.98 in Div. 3K (Fig. 3). Regression model fits improved when the comparisons were limited to common trips, as reflected by r^2 values ranging from 0.95 in Div. 3NO to 0.99 in Div. 3K. Limiting the comparisons to common trips captured less data on total landings and fishing hours (Tables 1-2) but improved the relationships across the two indices in all cases. Weekly fishing effort, by both measures, was generally higher in Div. 3KL than in the other divisions.

Annual VMS/DMP and logbook CPUEs trended together in all Div. (Fig. 4). Both indices showed highest CPUEs in Div. 3LNO, particularly from 2004 to 2006. The CPUEs have increased in the northern (2J3K) and southern (3Ps) divisions in recent years, while they declined along the Grand Bank in Div. 3LNO in 2007, following a period of relative stability from 2004 to 2006.

In Div. 2J, the relationship between weekly logbook and VMS/DMP CPUE was strong in 2004 (r^2=0.72), 2006 (r^2=0.96) and 2007 (r^2=0.73) but not in 2005 (r^2=0.08) (Fig. 5a). There were shorter fishing seasons with higher weekly CPUEs in 2006-07 than in the previous two seasons. In 2004-05, the mid-late season CPUEs were higher in the logbook index than in the VMS index in most weeks. A general pattern emerged of weekly declines in CPUE from the start to mid portions of the season with a subsequent increase from mid to late season in all years.

In Div. 3K, the relationships between the CPUE indices were relatively strong in all years, with r^2 ranging from 0.73 in 2007 to 0.98 in 2006 (Fig. 5b). Both indices showed higher weekly CPUEs in 2006-07 than in 2004-05. A progressively shorter season, starting and finishing earlier in the year, occurred from 2004 to 2006. In 2007, the season started in the third week of April and ended in the early part of July. Weekly CPUE generally decreased from the start to near the end of each season, excepting 2004, when a late-season re-opening resulted in relatively high CPUEs in September-October.

For Div. 3L, the correlations between CPUEs were generally strong in all years, with r^2 ranging from 0.46 in 2006 to 0.79 in 2004 and 2007. Weekly CPUE values remained at a comparable level from 2004 to 2007 and a pattern of declining CPUE from the start to the end of the fishery was apparent in all years. The fishery started about a month earlier (April 01) in 2006-07 than it did in 2004-05 but ended at about the same time (August-September) in all years.

In Div. 3NO, the correlations of weekly logbook vs. VMS CPUE were relatively strong in all years, with r^2 ranging from 0.45 in 2004 to 0.85 in 2007 (Fig. 5d). Weekly CPUE trends were variable and difficult to interpret in Div. 3NO both within and across seasons, but most weekly CPUE values were lower in 2007 than in the 2004-2006 period. As in Div. 3L, the fishery started about a month earlier (April 01) in 2006-07 than in 2004-05 but ended at about the same time (August-September) in all years.

In Subdiv. 3Ps, correlations of logbook and VMS CPUEs were stronger in 2004 and 2005 (r^2=0.78 and 0.94 respectively) than in 2006 and 2007 (r^2=0.14 and 0.07 respectively) (Fig. 5e). In 2004, both indices showed that an increase in weekly CPUE occurred from weeks 4 to 9 of the fishery before decreasing to the end of the season. Similarly, in 2005, the indices agreed that a decrease in CPUE occurred from weeks 7-8 to the end of the season. However, in 2006-07 no trend in CPUE was clear in either index, with high weekly variability in CPUE in both indices. The season started four to six weeks earlier in 2006-07 (April 01) than in 2004-05 and weekly CPUEs were higher in the latter portions of the seasons relative to 2004-05.

The rate of fishing efficiency exhibited a negative relationship with logbook CPUE in Div. 2J (r^2=0.66) (Fig. 6). Both the full-time and supplementary fleets had higher PPH when CPUE was lowest. There was no clear distinction in fishing efficiency between the two fleets over the four year period with both trending similarly. In Div. 3K, a negative relationship of PPH to CPUE also existed (r^2=0.27), as PPH was highest when CPUE was lowest. There was a clearer distinction between the fishing fleets in this division than in 2J, as the full-time fleet exhibited higher PPH values than the supplementary fleet throughout the time series. Interpretation of trends in Div. 3LNOPs is difficult as there is a lack of dynamic range or variability in CPUE over the time series (Fig. 4). In Div. 3LNO, this is particularly evident in the small supplementary fleets where CPUEs remained nearly equal in all four years (Fig. 6).

DISCUSSION AND CONCLUSIONS

For the first time in 2008, VMS data was used in the assessment of the Newfoundland & Labrador snow crab fishery. Until now, these data have been used primarily to monitor fishing vessels for compliance with spatial and temporal fishing regulations in this region. Our results showed that data available from VMS can be used to develop indices of fishing effort and fishery performance (CPUE) that are objective and independent of human error inherent in maintaining logbooks. Comparisons to logbook effort indices indicated that hours fished, from VMS, represent a reliable alternative to logbook fishing effort, the number of trap hauls. The two CPUE indices agreed well in annual, spatial and seasonal comparisons.

The use of VMS to validate logbook indices is important in that available observer data are insufficient in most areas (Dawe et al. 2006). Continued comparison is useful for resource assessment purposes to detect errors or compensate for incomplete provisional data from logbooks. The VMS/DMP indices can be reliably interpreted both independently of logbooks (all trips), as well as for data common to both sources. However agreement between indices improves when the indices are compared from common trips. This agreement validates the reliability of indices from both sources. However, the VMS/DMP data and indices have advantages above those from logbooks in that they are objective, accurate, complete and immediately available. Data can be electronically accumulated in real time whereas logbooks take longer to collect from many small, isolated communities throughout the Province. The element of logbook error in the NL snow crab fishery has not been quantified but VMS ensures spatial precision, with no element of human error and little element of inaccuracy, while DMP ensures accuracy in landings information.

The tight agreement in spatial distribution of logbook set positions and VMS fishing signals reduces uncertainty in interpreting both indices (Fig. 2). As there is little element of possible error in the VMS index, and the VMS index validates the logbook index, it might be inferred that the historical spatial information from logbooks used in the assessment of this fishery has been sufficiently reliable, at least since 2004. Likewise, the tight agreement in seasonal trends of CPUE from VMS/DMP and logbooks in all divisions (Fig. 4) validates the reliability of logbook catch rate data that has been traditionally used to assess this resource.

The differences we found between the CPUE indices likely reflect changes in fishing behaviour or resource abundance. For example, in Div. 2J, in 2005, there was poor agreement in trends between weekly logbook and VMS/DMP CPUE in the mid to late portions of the season (Fig. 5a). In most weeks of disagreement, the VMS-based CPUE was lower than the logbook-based CPUE, suggesting a higher level of relative effort in the VMS index. There was a high incidence of soft-shelled crab in the catches during this period, and DFO implemented a soft-shell protocol for observers to closely monitor catch rates of these recently molted animals (Dawe et al. 2006). Snow crabs captured and released as soft-shelled in a fishery may be particularly susceptible to mortality (Miller 1977). The poor agreement between CPUE indices likely reflects changes in fishing strategy, in response to soft-shelled crab. As regions of this fishery are closed for the remainder of the season once soft-shelled crab comprises at least 20% of the catch (Dawe et al. 2006), it seems logical that fishers would spend increased amounts of time on the fishing grounds, but fishing less gear (i.e. searching for new areas) in attempts to avoid or reduce capturing these crabs. This would result in a deflation of the VMS/DMP index relative to the logbook index, as the logbooks do not factor in time as a variable in calculating CPUE. The ability to detect changes in fishing behaviour that reflect events occurring in a fishery, particularly when a resource is in a vulnerable state, such as prominence of soft-shelled crab in this fishery, may allow for improved real-time management. This approach, of detecting changes in fishing behaviour can be extended to other fisheries to interpret changes in the dynamics of the exploited population such as abundance level, distribution, or migrations.

In this study, we demonstrated a negative relationship between CPUE and fishing efficiency (PPH) in Div. 2J3K. When CPUE was low, PPH was high. This implies that most vessels are able to deploy and retrieve gear at a faster rate when the catch per pot is relatively low. This is logical considering that low catch would mean little sorting time aboard a vessel. We were not able to show a relationship between CPUE and PPH in Div. 3LNOPs as CPUE trends changed little in these divisions for much of the study period. However, a continuation in monitoring this efficiency index in these divisions could prove beneficial. If this index were to suddenly change in either direction in these divisions it could be indicative of a change in catch rates, detectable in real time.

More advanced methods to detect changes in abundance or density through VMS may be developed with further research into understanding the behaviour of fishers. VMS tracks from fishing vessels are analogous to the tracks left by a predator in tagging studies. Marrell et al. (1980) interpreted the foraging success of female reindeer by interpreting the spatial movements of tagged animals, while other studies have utilized principles from physical and biological sciences such as Lévy flight analysis (Viswanathan et al. 2002) or random walk models (Bovet et al. 1988) to infer trends in prey density. Generally, when a prey population is in a healthy state, the movements of a predator are random, as opposed to when a prey population is depleted and predator movements are more directed. Behavioural studies using VMS in fisheries science, particularly in regions where the barriers to movements are few may advance the knowledge base and assessment capabilities of this and other fisheries.

Ours is not the first study to incorporate VMS for scientific utility in fisheries sciences. VMS technology has been exploited in complex fashion to measure trawling intensity on different substrates in the Irish Sea (Mills et al. 2004) and, linked with sonar, to create a virtual model to interpret effects on aggregating behaviour of Alaska Pollock caused by fishing (Barbeaux et al. 2005). However, until now data from VMS has not been used to develop indices of fishery performance to monitor status of a fishery resource. Many of the world's largest fisheries are currently monitored by VMS, but our study is the first to demonstrate its utility for fishery assessments. Our approach and methods are readily applicable to other commercial fisheries. Our comparison of VMS to logbook data validated recent trends in resource status inferred from logbook CPUE, offered some interpretation of events occurring in the fishery, and described further possible uses of these data for resource assessment and management of snow crab in Newfoundland and Labrador. The technology could similarly benefit other fisheries in our region and elsewhere around the world.

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Table 1. Sample Sizes (totals, all trips) of weekly offshore logbook and VMS effort, catch, and CPUE; 2004-07.

		Logbooks				VMS / DMP		
Division	Year	Number Sets	Number Traps	Catch (t)	CPUE (kg./trap)	Number Hours	Catch (t)	CPUE (kg./hr)
2J	2004	906	376,706	1,356	3.6	7,589	1,112	146.5
	2005	496	212,780	1,128	5.3	4,963	950	191.5
	2006	405	162,574	1,333	8.2	3,982	1,125	282.5
	2007	358	145,130	1,248	8.6	2,987	1,280	428.4
3K	2004	4,606	1,490,221	11,326	7.6	43,765	10,438	238.5
	2005	2,324	775,425	5,428	7	25,636	5,352	208.8
	2006	1,921	616,245	7,087	11.5	20,208	6,854	339.2
	2007	1,624	484,536	7,268	15	14,877	7,310	491.4
3L	2004	4,606	1,176,048	16,817	14.3	31,782	15,924	501.0
	2005	4,227	1,198,297	16,656	13.9	35,002	16,547	472.7
	2006	4,027	1,167,764	15,648	13.4	37,308	16,720	448.1
	2007	4,358	1,346,747	15,757	11.7	36,794	16,237	441.3
3NO	2004	1,045	283,065	4,331	15.3	5,677	2,822	497.1
	2005	1,036	281,069	3,963	14.1	5,811	2,741	471.6
	2006	682	209,642	3,228	15.4	6,604	3,050	461.8
	2007	731	243,658	2,997	12.3	6,408	2,581	402.8
3Ps	2004	1,783	374,261	3,032	8.1	9,858	2,318	235.2
	2005	1,376	366,167	2,270	6.2	10,999	1,853	168.5
	2006	1,030	262,525	1,969	7.5	9,496	1,826	192.3
	2007	1,134	289,571	2,259	7.8	9,230	1,974	213.9
Total		38,675	11,462,431	125,101	10.9	328,976	119,014	361.77

Table 2. Sample Sizes (totals, common trips) of weekly offshore logbook and VMS effort, catch, and CPUE; 2004-07.

		Logbooks				VMS / DMP		
Division	Year	Number Sets	Number Traps	Catch (t)	CPUE (kg./trap)	Number Hours	Catch (t)	CPUE (kg./hr)
2J	2004	607	241,303	925	3.8	6,910	916	132.6
	2005	376	154,107	882	5.7	4,818	880	182.7
	2006	306	115,755	978	8.5	3,612	946	262.0
	2007	226	89,490	776	8.7	2,763	799	289.3
3K	2004	3,729	1,195,846	9,286	7.8	39,717	9,318	234.6
	2005	2,106	702,472	4,927	7.0	24,082	4,926	204.5
	2006	1,673	539,007	6,216	11.5	19,167	6,224	324.7
	2007	1,235	366,133	5,659	15.5	14,137	5,895	417.0
3L	2004	3,763	961,246	14,018	14.6	28,644	14,089	491.9
	2005	3,813	1,075,015	14,950	13.9	32,335	15,046	465.3
	2006	3,306	973,188	13,102	13.5	31,404	13,268	422.5
	2007	3,323	1,055,908	12,186	11.5	32,274	12,639	391.6
3NO	2004	575	170,422	2,632	15.4	5,431	2,652	488.3
	2005	567	166,997	2,535	15.2	5,568	2,524	453.4
	2006	545	168,902	2,603	15.4	5,990	2,610	435.8
	2007	513	184,149	2,130	11.6	5,937	2,182	367.6
3Ps	2004	1,292	260,910	2,129	8.2	9,469	2,137	225.7
	2005	1,063	283,502	1,743	6.2	10,492	1,747	166.6
	2006	815	208,787	1,575	7.5	8,679	1,573	181.2
	2007	775	200,603	1,567	7.8	8,466	1,610	190.2
Total		30,608	9,113,742	100,819	11.1	299,895	101,981	340.1

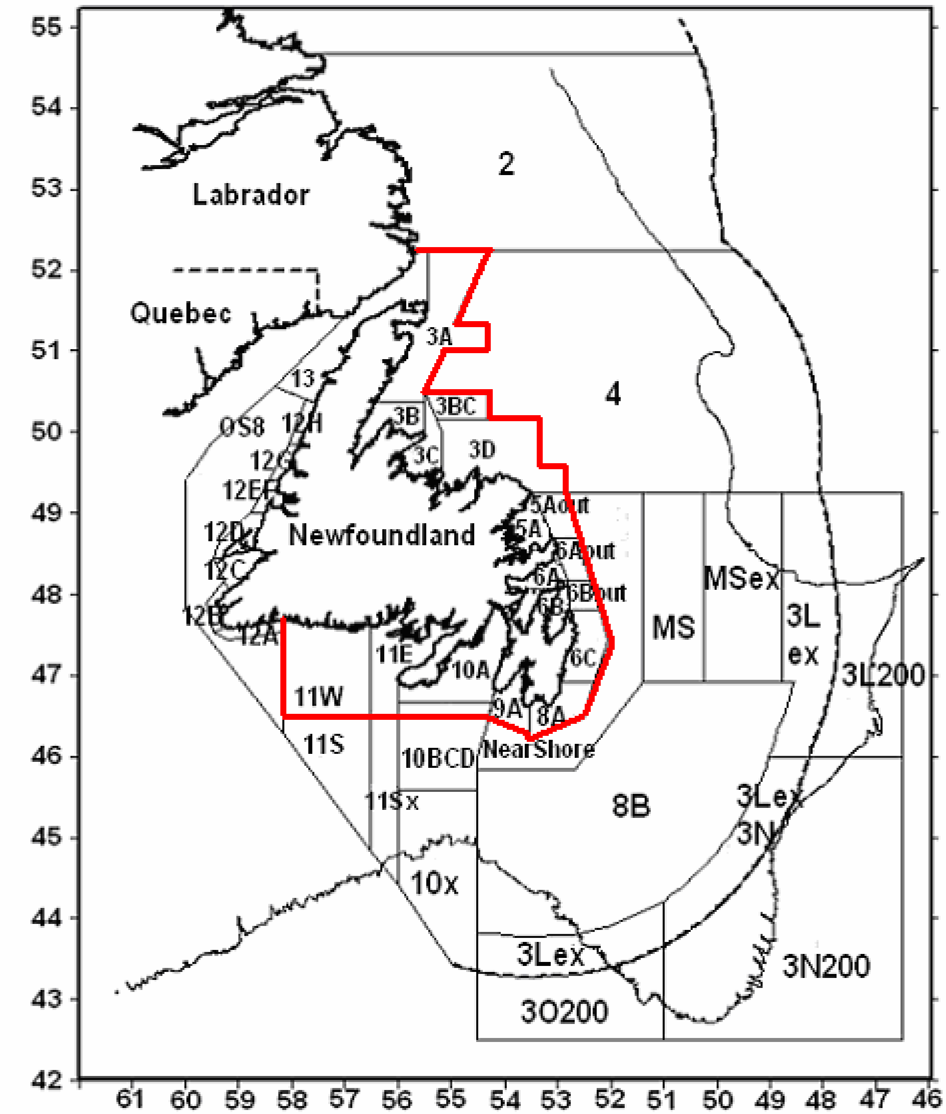

Figure 1. Newfoundland & Labrador Crab Management Areas (CMAs). ***Red line shows the separation between inshore vs. offshore CMAs.***

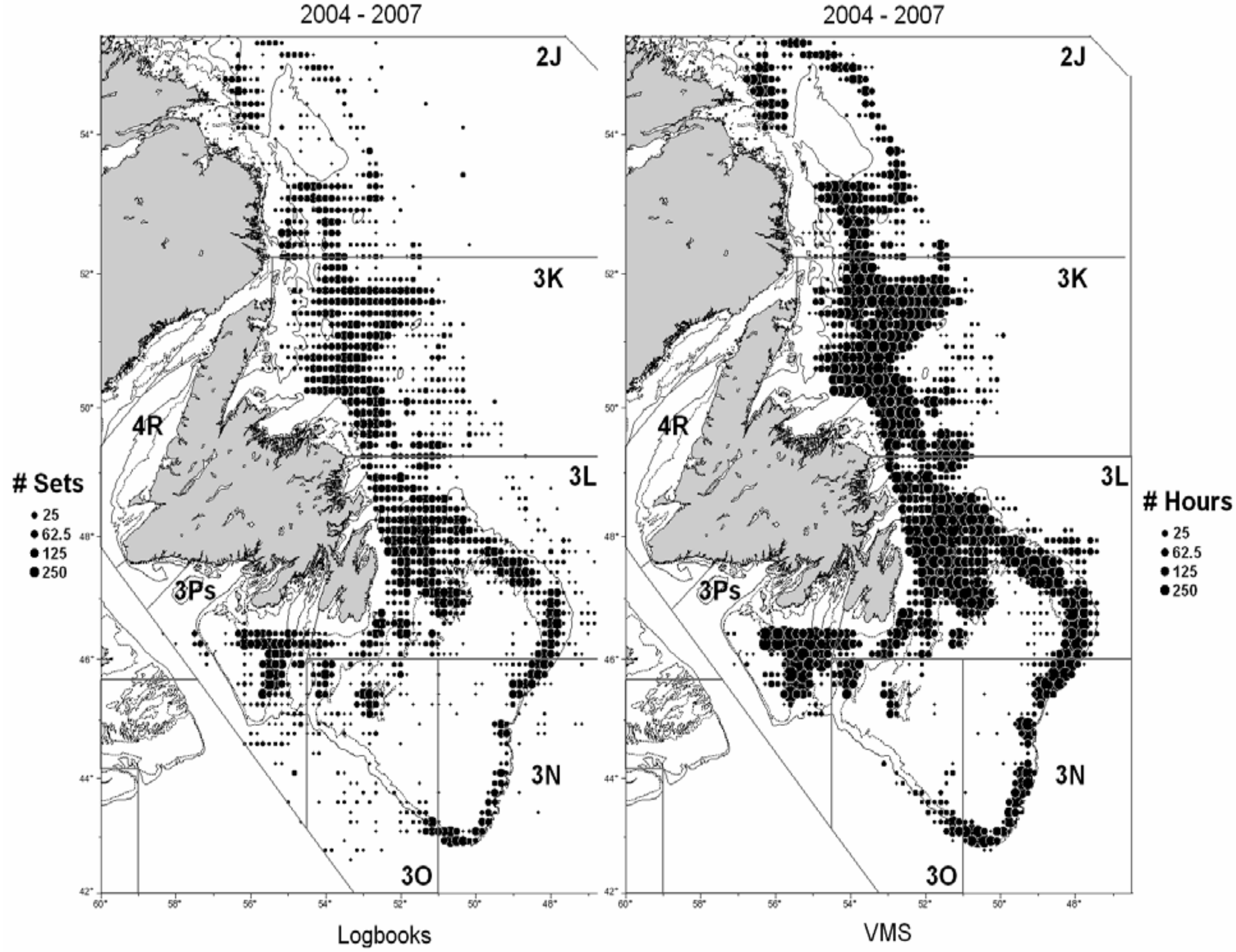

Figure 2. Spatial distribution of snow crab fishing sets from logbooks versus VMS fishing effort (hours fishing) from offshore CMAs in NAFO Divisions 2J3KLNO and Subdivision 3Ps during 2004-07.

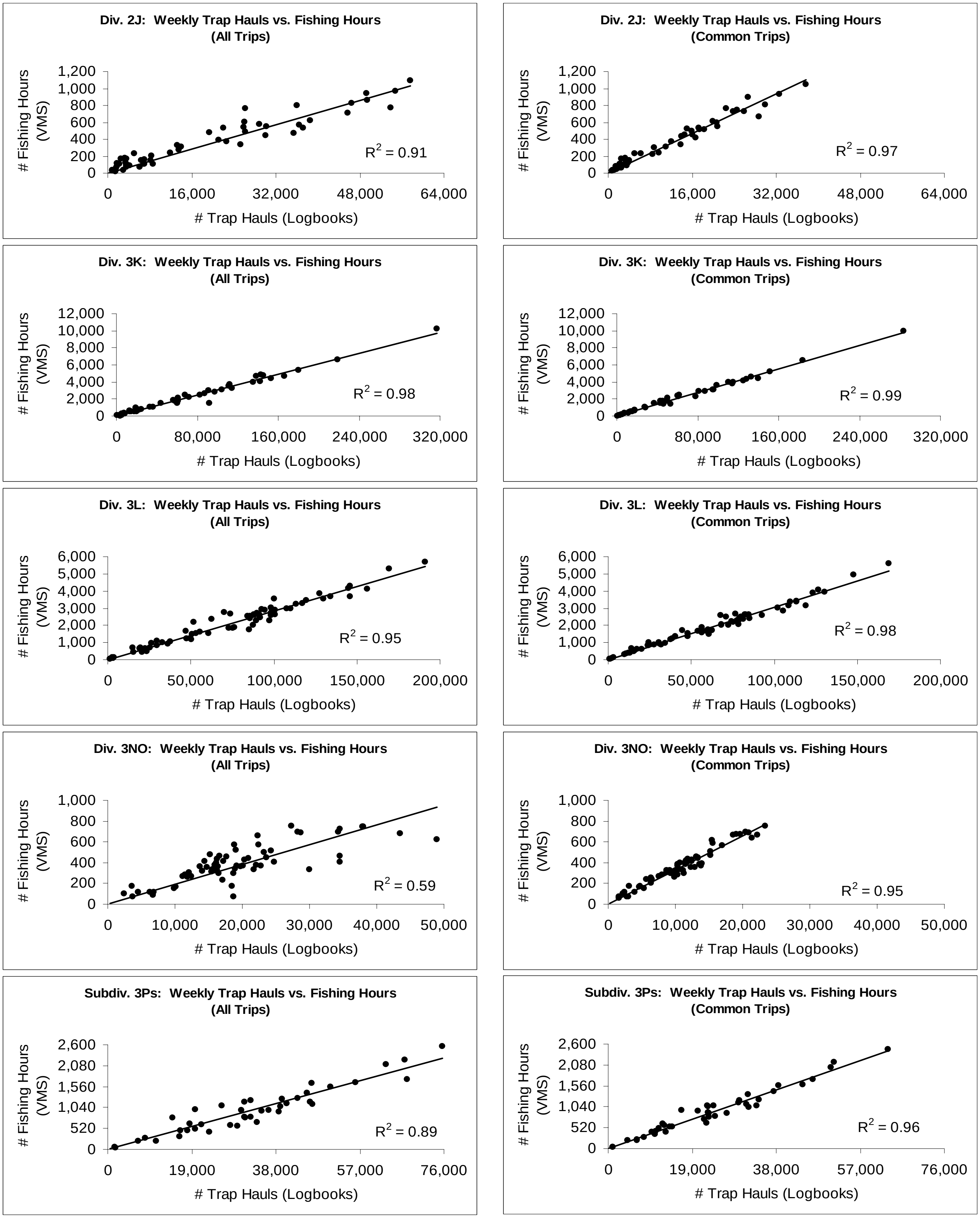

Figure 3. Linear regression describing the relationship between logbook (trap hauls) versus VMS (fishing hours) effort by Division. Left panels show the relationships for all trips and right panels show the relationships for common trips.

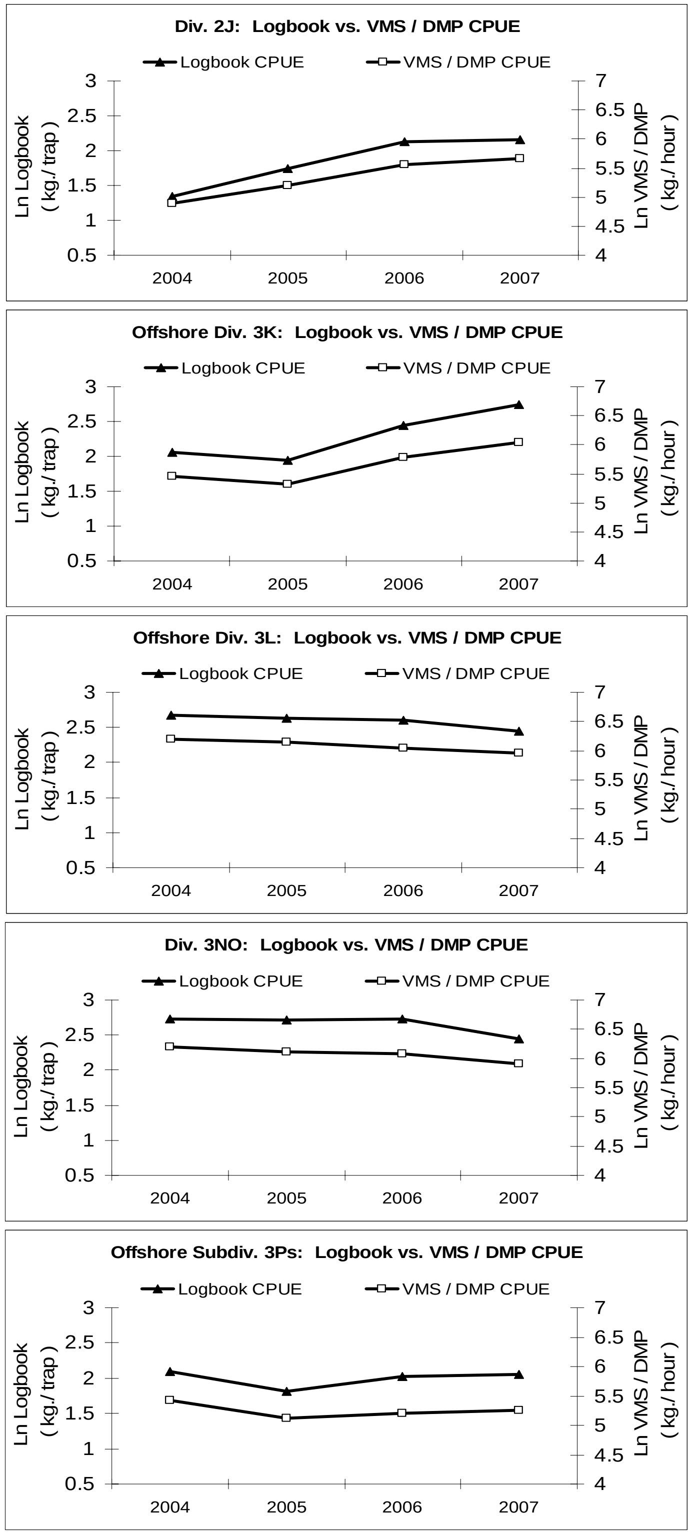

Figure 4. Comparison of annual trends in CPUE for common trips between logbooks and VMS by Division from 2004 to 2007.

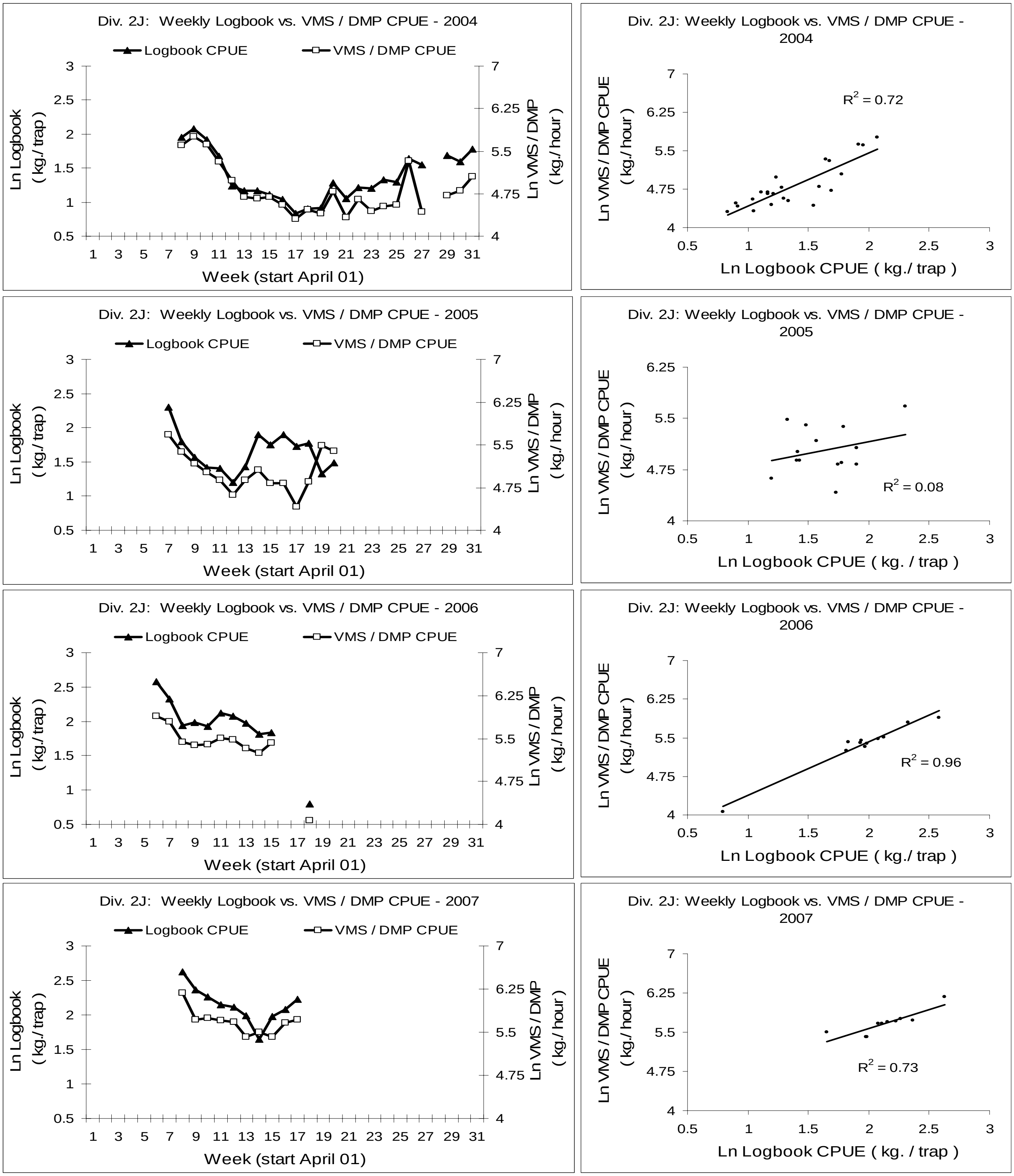

Figure 5a-e. Trends for common trips in weekly logbook CPUE versus VMS CPUE by division from 2004 to 2007 (left panels) and linear regressions describing their relationship (right panels). a. Div. 2J.

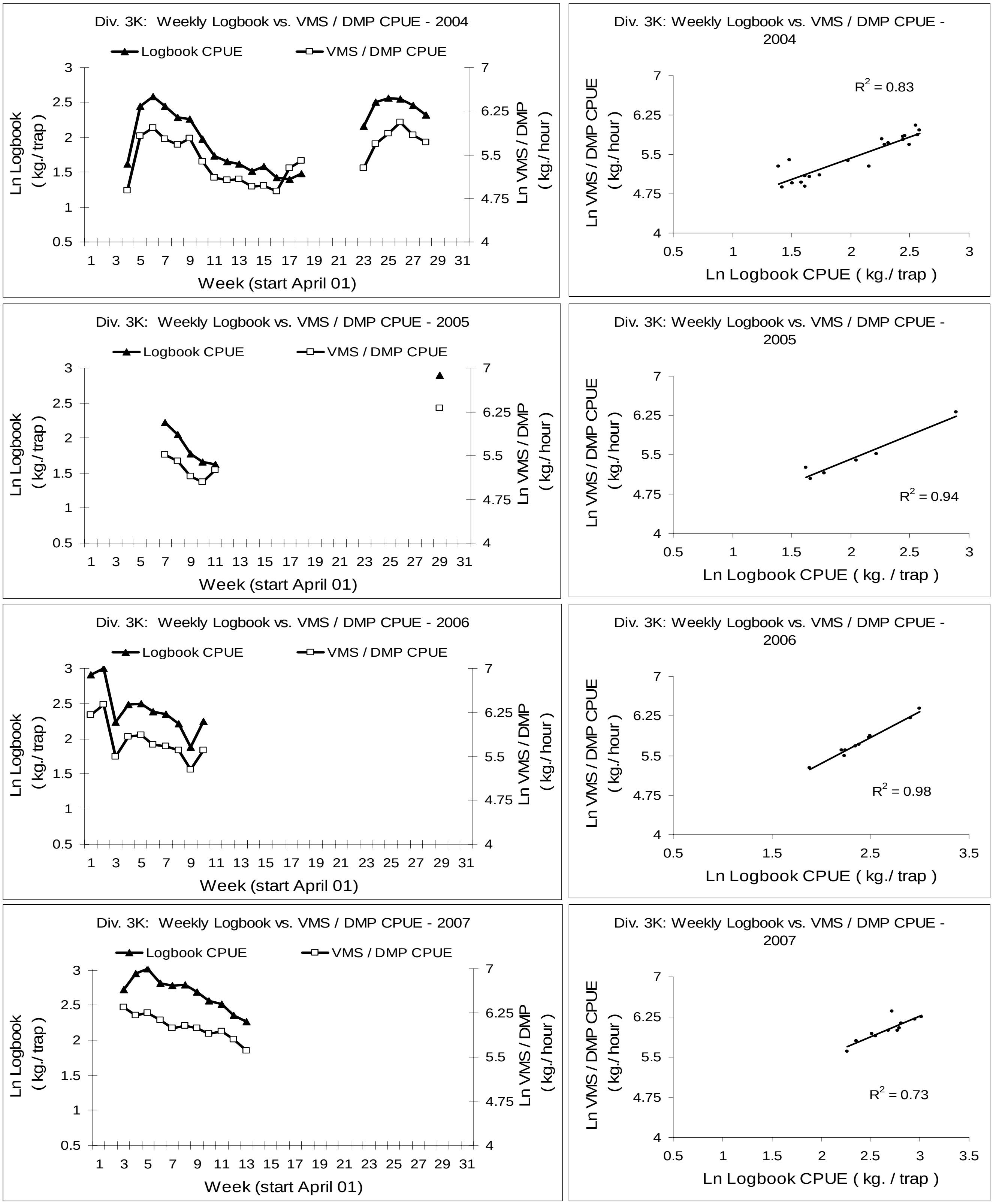

Figure 5b. Div. 3K.

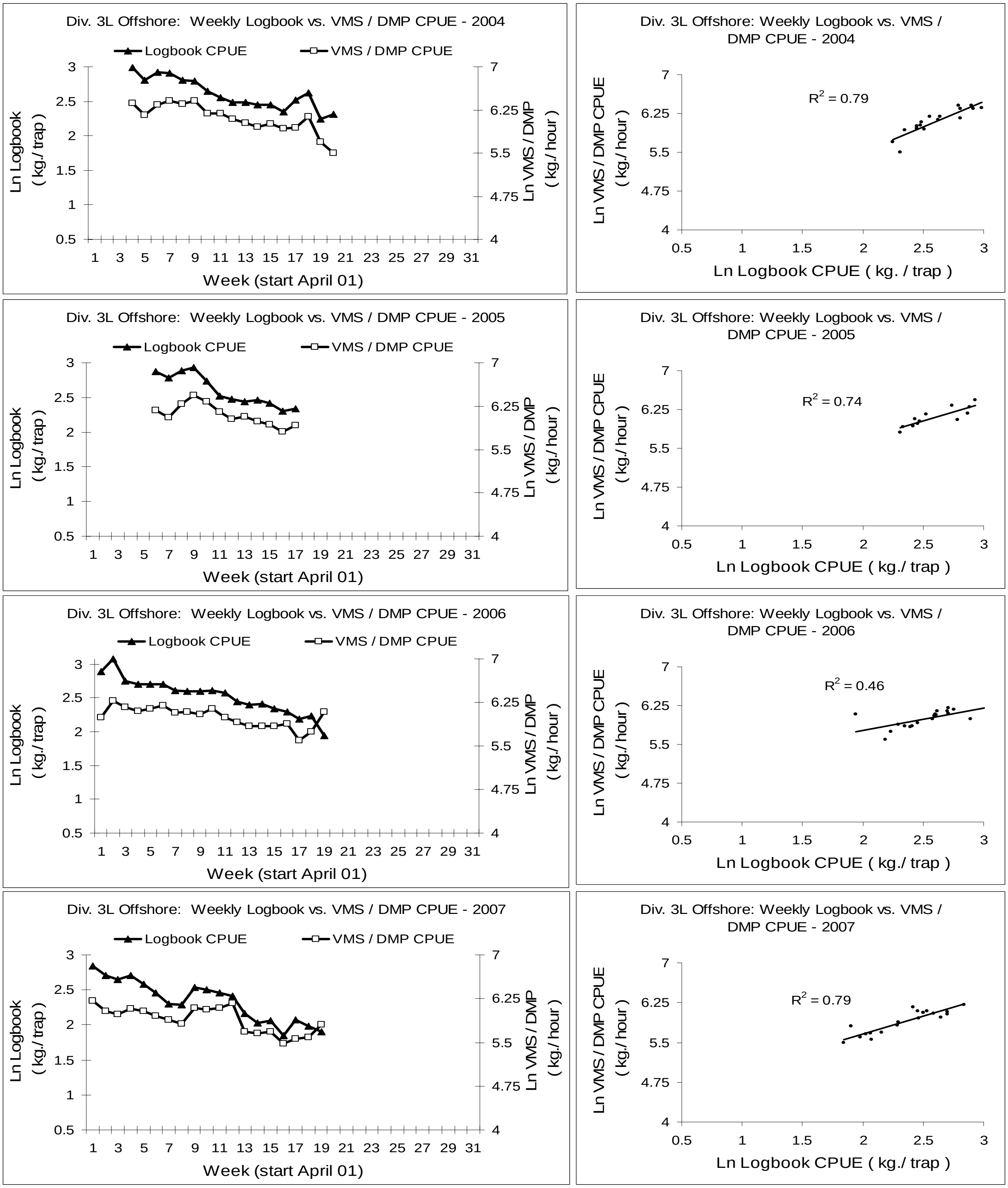

Figure 5c. Div. 3L.

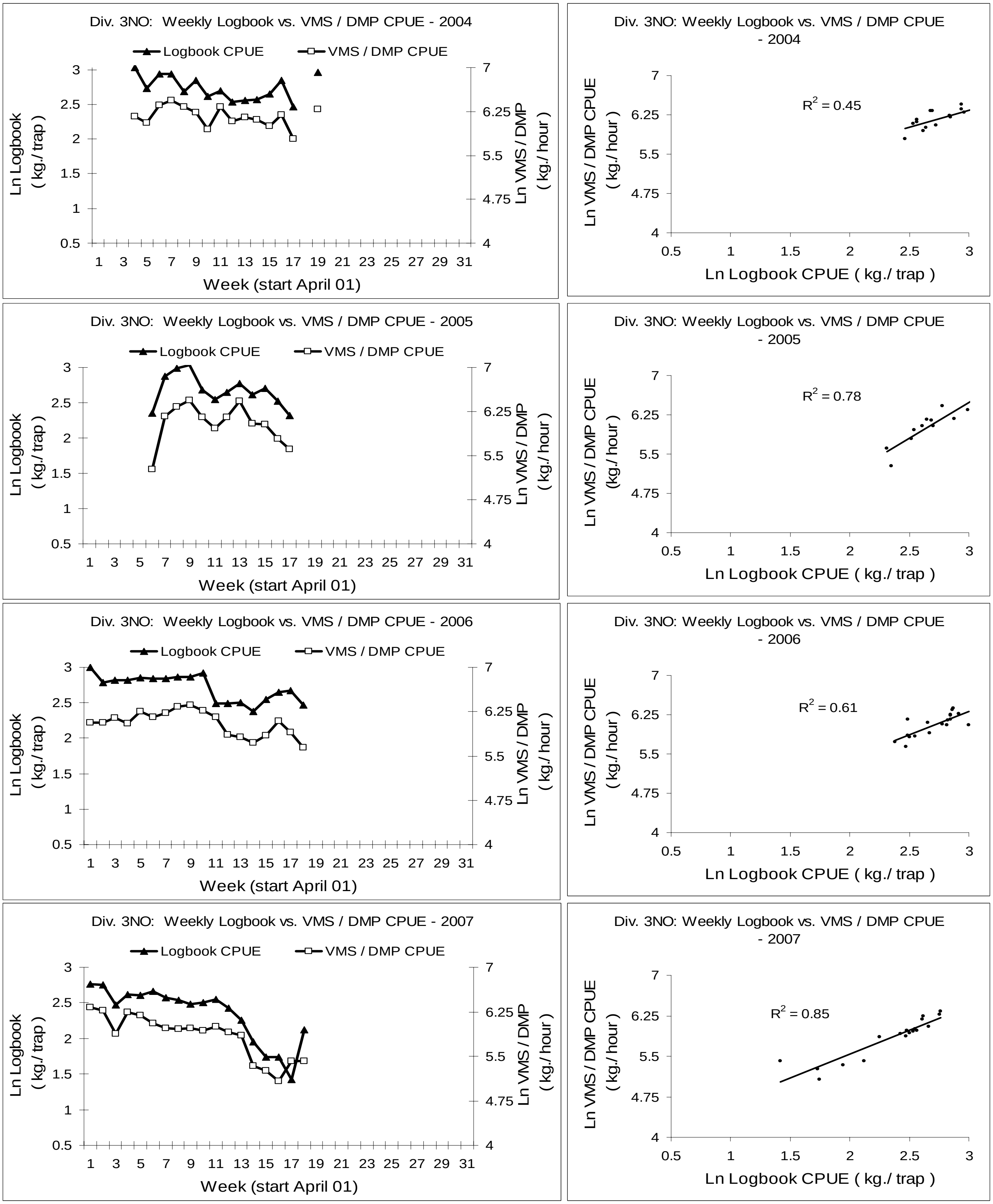

Figure 5d. Div. 3NO.

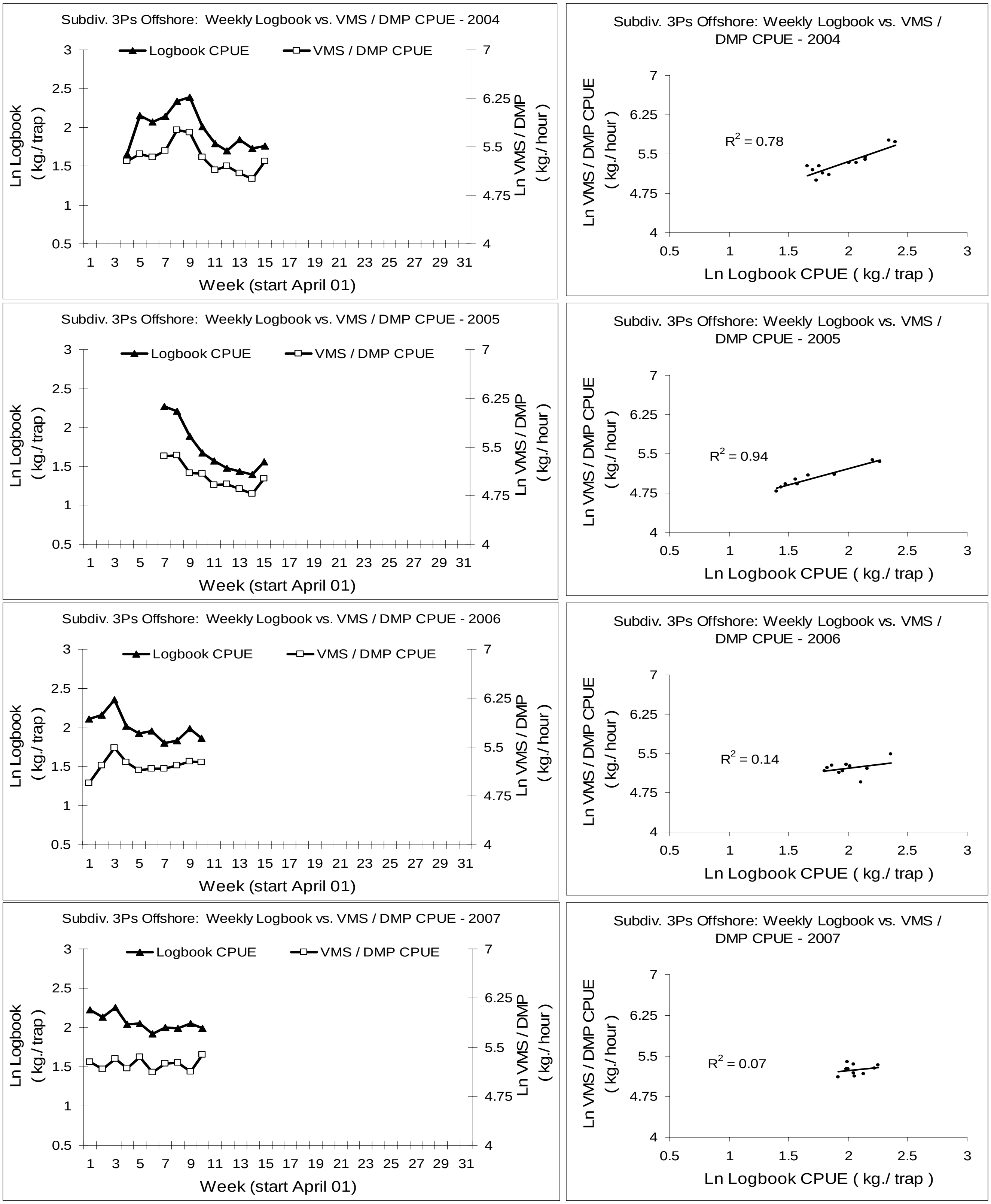

Figure 5e. Subdiv. 3Ps.

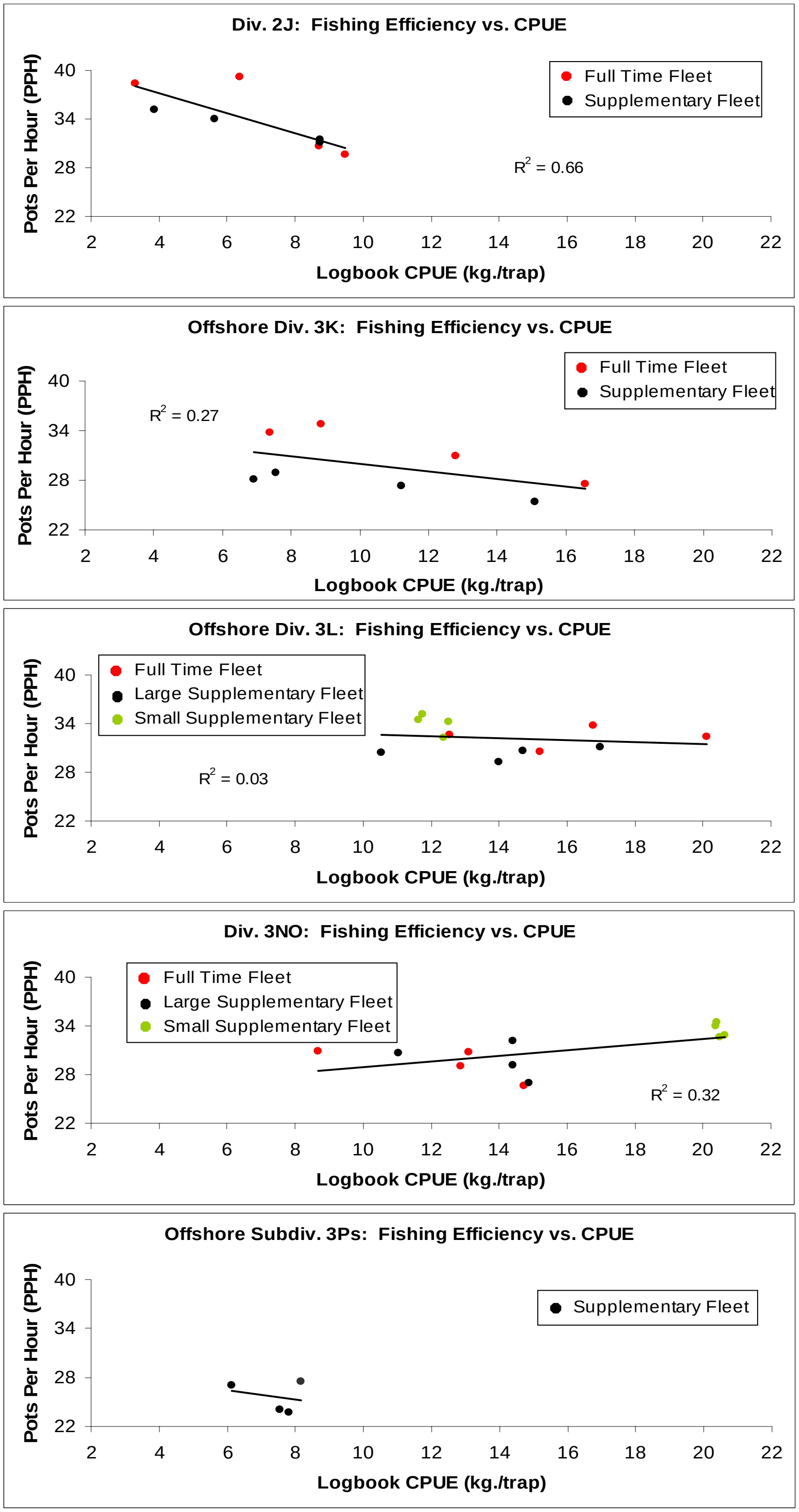

Figure 6. Relationship of fishing efficiency (pots per hour) from fleet-specific VMS data with logbook CPUE, by NAFO Division.