Abundance and size distribution of the humphead wrasse (*Cheilinus undulatus*) in Raja Ampat waters, West Papua Province, Indonesia

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Abstract. The aim the present study was to investigate the natural abundance and size of the humphead wrasse (HHW), *Cheilinus undulatus,* in Raja Ampat waters. Density surveys was done using a modified Underwater Visual Census (UVC) with Global Positioning System (GPS) performed at 4 sub-districts and 1 marine protected area. The results were combined and compared with the previous studies. The abundance of *C. undulatus* in North Salawati Sub-District was 6.61 individuals ha^{-1}, of which density is moderately correlated with area surveyed rather than distance elapsed. Fish size was dominated by juvenile and pre-adults phase, putting higher risk of population decreased caused by fishing. The accumulation abundance in *C. undulatus* based on survey data in 2012-2016 was 3.36 individuals ha^{-1} with a total surveyed area along 105.105 km with covering an area of 953107 m^2. Both previous and present studies were in agreement that habitat protection by avoiding destructive fishing is the most appropriate management measure to recover *C. undulatus* population.

Key Words: *Cheilinus undulatus,* density survey, accumulative abundance, habitat protection.

Introduction. The humphead wrasse (HHW) (*Cheilinus undulatus* Rüppell, 1835) is traded as live reef fish food (LRFF) where Indonesia is among the principal producers that exports this fish species to Hong Kong and China (main markets), beside Taiwan and Singapore (Sadovy & Vincent 2002; Greenpeace 2004; Suharti 2009; Wu & Sadovy de Mitcheson 2016). An excessive demand and in the following of climbing price is the root for the highly exploitation of this species. Recently, 1.5-2.5 kg of *C. undulatus* costs 320 US$ (Wu & Sadovy de Mitcheson 2016). Based on these facts, this rare coral species is being threatened by extinction as it is exploited largely at juvenile stage, whereas *C. undulatus* is naturally hermaphroditic animal with high longevity and slow to mature. The conservation status of *C. undulatus* has been classified into “Endangered” species since 2004, imposing to the enactment of Appendix II CITES.

A significant decreased in Indonesian *C. undulatus* population has been reported (Suharti 2009), of which Sadovy et al (2007) stated that in low fishing pressure area the *C. undulatus* population might reached 10 individuals ha^{-1}. As reported by Gillet (2010), that Colin in 2005 obtained the abundance of *C. undulatus* in Bali Kangean and Raja Ampat ranged between 0.04-0.86 individuals ha^{-1} along 125 km survey track; recently, Rahman & Syam (2015) reported that in Sembilan Islands of Sinjai and Takabonerate was between 0.0-6.3 and 0.0-4.17 individuals ha^{-1}, respectively, whereas none *C. undulatus* was found in Maumere Bay.

In Bird’s Head Seascape region of West Papua Province, the trade of LRFF has been concentrated in Raja Ampat Regency since 1980, of which *C. undulatus* is the main target (Sadovy & Liu 2004; Huffard et al 2012). As Indonesian quota for this species has been reduced from 8000 in 2005 to only 2000 tails (individual fish) in 2012 ever since (Wu & Sadovy de Mitcheson 2016), consequently the quota allocation for West Papua Province has been dropped significantly from 2000 in 2009 and for 2016 ahead become 600 tails (DJKSDAE 2015), affecting the socio-economic life of local fishermen. In fact, there has been a paradox condition where the reduction in national quota in one hand, and the export realization has never been achieved in another. Such a contradiction, according to Edrus & Suman (2015) might be addressed to: firstly, the fact that the natural population of *C. undulatus* is decreasing at which it has presumably declined to 50% (Russell 2004), especially during the last 10-15 years (Sadovy 2006a); secondly, uncontrolled illegal trading including direct sea transportation (Sadovy 2006a; Widayatun et al 2007) and violation on permits as well as regulations (Sadovy & Suharti 2008), therefore the actual number of fish traded remains unknown.

Understanding on abundance and size of *C. undulatus* is of importance information towards better management. Survey and monitoring on abundance, at the same time will provide information about exploitation level, habitat size and conditions. A good monitoring data would be relevant rationale to propose a new quota allocation by Indonesian Institute of Sciences (LIPI) as scientific authority. By combining the previous and recent data, the present study has been aimed to demonstrate the importance of comprehensive monitoring of *C. undulatus* population in Raja Ampat waters.

Material and Method

Survey location and time. The survey for *C. undulatus* was conducted within Raja Ampat waters consisting of 4 sub-districts and 1 marine protected area of which each location was visited once at different years of 2012, 2013, 2015, and 2016 (Table 1). Site designation taken consideration at satellite imagery analysis, field observation, and information from local fishermen. While North Salawati Sub-District was primary data for 2016, the rests were secondary ones obtained from LPSPL (*Loka Pengelolaan Sumberdaya Pesisir dan Laut* or Regional Implementation Unit for Coastal Resource Management) in Sorong, West Papua Province (2012; 2013; 2015). Figure 1 showed the location where primary data collected in North Salawati Sub-District, and Table 1 listed the whole study locations mentioned in the present paper.

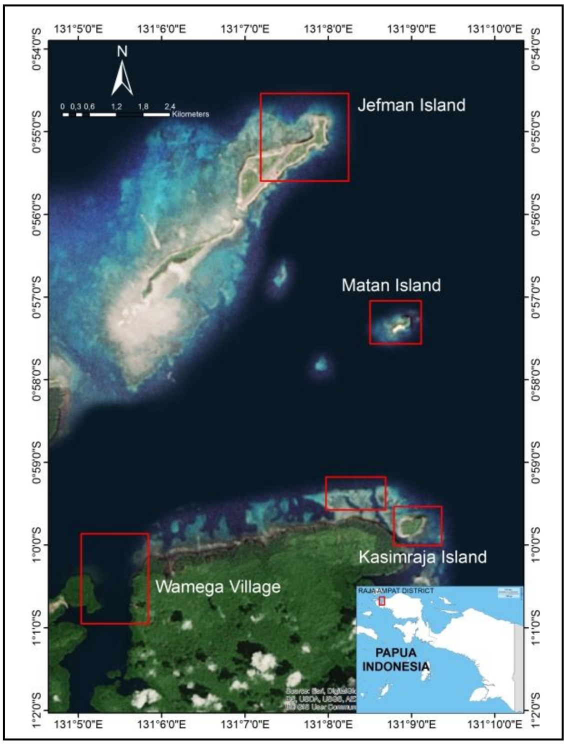

Figure 1. Map showing the sites of abundance survey for *Cheilinus undulatus* in North Salawati Sub-District, Raja Ampat Regency.

Table 1

Date and location for abundance survey of *Cheilinus undulatus* in Raja Ampat Waters, West Papua Province. Note that primary data source was collected from North Salawati Sub-District (August 2016)

Date	*Location*
	Meos Mansuar Sub-District
7-9 March 2012	Kri-Mansuar Island
10 March 2012	Kabui Bay
12 March 2012	Pianemo
	Misool Sub-District
6 March 2013	Balbulol
6 March 2013	Campedak
7 March 2013	Namlol
8 March 2013	Harapan Jaya
9 March 2013	Wayaban
9 March 2013	Banyaganan
	West Waigeo Sub-District
13 March 2013	Manyaifun
13 March 2013	Meos Manggara
14 March 2013	Bianci
15 March 2013	Mutus
	Marine Protected Area Ayau-Asia Islands
4 & 6 November 2015	Ayau Besar (South)
5 November 2015	Ayau Besar (North)
4-6 November 2015	Ayau Besar (West)
6 November 2015	Ayau Besar (East)
6 November 2015	Ayau Kecil (East)
7 November 2015	Ayau Kecil (North)
7 November 2015	Ayau Kecil (West)
7 November 2015	Ayau Kecil (South)
	North Salawati Sub-District
09 August 2016	Jefman Island
10 August 2016	Wamega Village (North)
10 August 2016	Kasimraja Island
11 August 2016	Matan Island
11 August 2016	Wamega Village (West)

Density survey. Survey of *C. undulatus* refers to "GPS (Global Positioning System) Density Survey" developed by Colin from the Coral Reef Research Foundation (Colin 2006; Sadovy 2006b). This technique is modified from the conventional underwater visual census (UVC) survey (English et al 1997) with typically 50 or 150 m long transects; it is found that the distance covered by UVC transect is unsuitable to obtain abundance data for uncommon and wideranging species like *C. undulatus* (Sadovy 2006a). In comparison to UVC survey, the GPS survey takes into account both distance and reef areas. A greater detail of GPS density survey is found in Sadovy (2006b).

Fish within a predetermined distance either side of the swim track (up to 15 m in clear water, giving a total ‘swath’ or scan width of 30 m) were surveyed by swimming along a reef feature or in a relatively straight line at a steady pace or drifting with currents. The real time that any target fish is observed and recorded on an underwater slate, and the length of the fish is noted (Sadovy 2006b). Fish length can be estimated visually (Samoilys 1997). Fish abundance is calculated based on the number of fish recorded divided the area in ha, where the area is the length of the track (m) multiplied by width (m); area in m^2 was converted to ha.

Fish size is determined based on length frequency distribution (Walpole 1982), taking into account the number of class length, width of class interval, and class frequency. Number of class is determined by using Sturgess Law, i.e. K (class number) = 1 + (3.32 Log n). Correlation analysis was performed in comparing the relationship between abundance and distance or area surveyed (Quinn & Keough 2002).

Results and Discussion

Density survey applicability. Table 2 showed the recorded data obtained during observation of *C. undulatus* applying GPS density survey method in North Salawati Sub-District. The records are kept continuously from one location to another where visit duration of each sub-location was for one day of snorkeling. Of each track, the distance and swath ranged between 7-15 m so that the area in m^2 could be determined. Once the observer encountered *C. undulatus*, the corresponding coordinate point is recorded, hence, the sum of elapsed distance, area, and number of fish are obtained. Information about coordinate, elapsed track, fish encounter with corresponding number is clearly shown spatially (Figure 2).

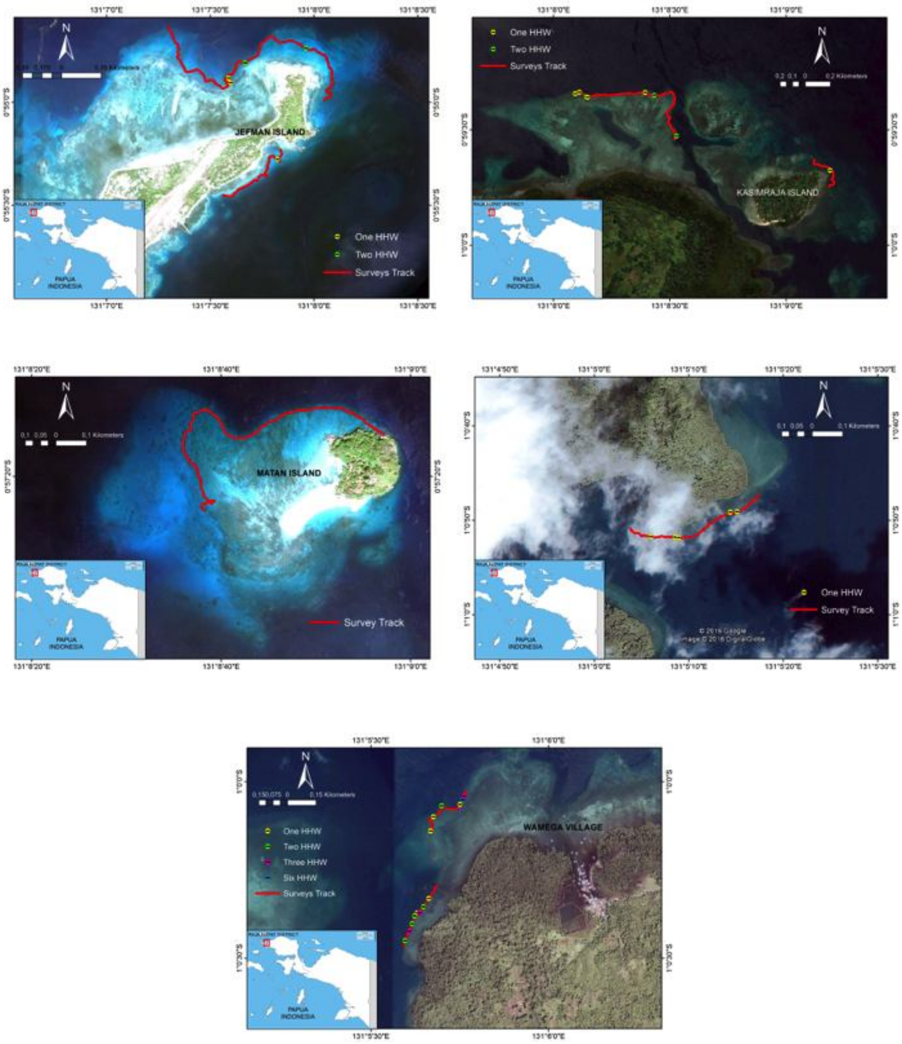

Figure 2. Overlaid tracks and number of encountered *Cheilinus undulatus*, in North Salawati Sub-District location of Raja Ampat waters of West Papua Province.

All information shown in Table 1 and Figure 2 is to prove that density survey may be the most appropriate method in surveying the presence of *C. undulatus* in their habitat in terms of number and size within certain area. The maximum size of *C. undulatus* reach more than 2 m and it was reported in www.fishbase.org to be 229 cm and 190 kg of which the commonest is approximately 60 cm. It may save to state that the larger animal the lower the abundance, so it happens to *C. undulatus* (e.g. Sadovy 2006b). The previous UVC method might be unable to encounter *C. undulatus* within the designed line transect of 50-100 m length, leading to high probability of underestimate result. On the contrary, the representativeness of this survey was presumably high, as the distance and area covered was proportional with the size of coral reefs habitat. To the later, the area has been dynamically adjusted with water visibility that determines swath factor. By comparing the previous and present data for 5 years period, it is likely that information presented is highly consistent, therefore, it may be concluded that the results would give best performance for *C. undulatus* population in Raja Ampat waters.

C. undulatus abundance. The present results in North Salawati Sub-District showed that *C. undulatus* abundance in average was 6.61 individuals ha^{-1} along 8.096 km track length and 84685 m^2 area, where 56 individual fish was encountered. By sub-location, fish number ranged between 0-38 tails, being the highest found in Wamega Village (West), whereas no single fish has been found on Matan Island (Table 2). An outstanding number of fish in Wamega Village (West) compared to other sites was due to the absent destructive fishing in this site. Fish bombing in Jefman Island, Wamega Village (North), Kasimraja Island, and Matan Island has caused high percentage of corals rubble, destructing habitat type of all many coral reefs fishes. On the extreme figure, the heaviest fish bombing effect was found on Matan Island where none of *C. undulatus* has been observed; this site was strongly characterized by the highest percentage of coral rubble. Mcmanus et al (1997) has estimated that blasting effect from fish bombing could destroy the reefs within the radius of 0.5-1.5 m, i.e. the overspread of produced coral rubble by each time of bombing is 1.57-4.71 m^2. Though the estimation on the physical effect is rather over simplified, the ecological effect is believed to be more complicated and severe. Sadili et al (2015) pointed out that in terms of habitat quality, the destruction of coral reefs is among the causes of the depletion of *C. undulatus*. Additionally, the discrepancy in fish number between the sites may be that of variation in area and distance covered, proportion of corals cover and the presence of sea grass and macro algae of which facilitate fish and habitat adaptation and association.

Of the previous surveys in 2012-2015 periods, it is clearly shown that the highest abundance in *C. undulatus* was found in the MPA of Ayau-Asia Islands (Table 3). Since the main goal of MPA is to maintain biodiversity and the area is protected from fishing activity (no take zone area), therefore the threats on species is highly decreased (Li 2000). It is likely that that conservation effort has positive impact to the recovery of *C. undulatus* population (Edrus & Suman 2015).

In nature the adult *C. undulatus* are commonly found at depth to 100 m (Sadovy et al 2003). However, they show high affinity with the shallower depths such as reef flat and reef crest. This is influenced by the degree of pressure on this species and coral reefs conditions as their habitat. An abundance survey in Banda Sea water in 2012 using UVC and snorkeling has recorded 90 tails of *C. undulatus* of which 25 was the adults with 60-80 cm in length (LPSPL Sorong 2012b). Such a good figures were believed as the results of the revitalization of the conservation area, where no fishing zone has been applied. Moreover, exploitation was expected to low as the local people do not consume *C. undulatus*, therefore it was not the target species.

Having compared between the previous and the present results (Table 3), a simple correlation analysis showed that the area moderately correlated with the number of fish in 10000 m^2 (R^2 = 0.67), whereas no correlation was found with the distance (R^2 = 0.23). By sub-location basis, the values of R^2 highly varied from 5% (North Salawati) to 99% (Meos Mansuar). This is to say that a highest density of *C. undulatus* in North Salawati (6.61 individuals ha^{-1}) was uncorrelated with the area surveyed. On the contrary, in Misool with the lowest *C. undulatus* density of 2.83 individuals ha^{-1} was slightly correlated (R^2 = 68%). In terms of area, North Salawati Sub-District is one-third as big as Meos Mansuar (Table 3). Such discrepancy might be caused by variation in habitat conditions. In Meos Mansuar waters the abundance of *C. undulatus* has increased from 0.86 in 2005 to 3.05 in 2012 (LPSPL Sorong 2012a) where fish abundance concentrated in Kri-Mansuar Island (Table 3). The island has been developed for conservation and eco-tourism site since 2005 where fishing has been prohibited ever since. Such management measure may appropriate to increase the number of *C. undulatus* in Meos Mansuar. This is to say that both the previous and present results showed agreement that the number of *C. undulatus* in certain area fully depends on the habitat conditions in terms of the presence or absent of fishing and habitat destruction.

Table 2

Example of data recorded in surveying *Cheilinus undulatus* in North Salawat Sub-District of Raja Ampat Regency

Location	*Coordinate*		*Date*	*Time*	*Distance (m)*	*Swath (m)*	*Number C. undulatus*	*Cummulative number C. undulatus*
	Longitude	*Latitude*						
Jefman Island								
Start	131.1342	-0.916517	08/09/2016	9:02:05	7	10	-	-
	131.1327	-0.9123	08/09/2016	9:29:05	743	10	2	2
	131.1278	-0.913483	08/09/2016	9:57:05	1470	10	2	4
	131.1265	-0.914717	08/09/2016	10:10:05	1722	10	1	5
	131.1266	-0.915083	08/09/2016	10:20:05	1891	10	1	6
	131.1304	-0.921267	08/09/2016	14:06:00	3140	7	1	7
Finish	131.1260	-0.924167	08/09/2016	14:47:45	3931	7	-	7
Wamega Village (North)								
Start	131.1348	-0.988967	08/10/2016	10:37:29	3935	15	-	7
	131.1349	-0.98905	08/10/2016	10:38:59	3952	15	1	8
	131.1352	-0.98895	08/10/2016	10:40:14	3989	15	1	9
	131.1357	-0.989283	08/10/2016	10:43:14	4058	15	2	11
	131.1358	-0.989317	08/10/2016	10:43:59	4071	15	1	12
	131.1399	-0.988967	08/10/2016	11:01:44	4547	15	1	13
	131.1406	-0.989167	08/10/2016	11:05:29	4631	15	2	15
	131.1422	-0.992117	08/10/2016	11:39:44	5241	15	2	17
Finish	131.1420	-0.992333	08/10/2016	11:42:44	5292	15	-	17
Kasimraja Island								
Start	131.1521	-0.993817	08/10/2016	13:06:23	5297	7	-	17
	131.1532	-0.994583	08/10/2016	13:12:38	5490	7	1	18
Finish	131.1531	-0.995767	08/10/2016	13:21:08	5681	7	-	18
Matan Island								
Start	131.1492	-0.954283	08/11/2016	10:57:01	5682	15	-	18
Finish	131.1440	-0.95655	08/11/2016	11:42:31	6834	15	-	18
Wamega Village (West)								
Start	131.0844	-1.014133	08/11/2016	15:22:22	6836	3	-	18
	131.0850	-1.014367	08/11/2016	15:26:52	6913	3	1	19
	131.0857	-1.014383	08/11/2016	15:31:37	6995	3	1	20
	131.0858	-1.0144	08/11/2016	15:32:37	7006	3	1	21
	131.0873	-1.01365	08/11/2016	15:44:07	7209	3	1	22
	131.0875	-1.013633	08/11/2016	15:46:07	7236	3	1	23
	131.0933	-1.0075	08/11/2016	17:20:33	7360	10	2	25
	131.0935	-1.00705	08/11/2016	17:24:48	7417	10	3	28
	131.0936	-1.0067	08/11/2016	17:27:48	7462	10	2	30
	131.0937	-1.006333	08/11/2016	17:31:03	7504	10	2	32
	131.0939	-1.006183	08/11/2016	17:33:33	7533	10	1	33
	131.0940	-1.006183	08/11/2016	17:34:18	7546	10	3	36
	131.0941	-1.0059	08/11/2016	17:36:48	7588	10	2	38
	131.0944	-1.0055	08/11/2016	17:39:03	7641	10	1	39
	131.0945	-1.002317	08/11/2016	17:54:18	7724	7	1	40
	131.0946	-1.00165	08/11/2016	17:59:03	7822	7	1	41
	131.0950	-1.001133	08/11/2016	18:02:18	7905	7	2	43
	131.0958	-1.00115	08/11/2016	18:06:18	8006	7	3	46
	131.0959	-1.001067	08/11/2016	18:07:03	8018	7	1	47
	131.0960	-1.00085	08/11/2016	18:09:03	8044	7	6	53
	131.0960	-1.000667	08/11/2016	18:10:33	8067	7	3	56
Finish	131.0961	-1.000433	08/11/2016	18:11:33	8096	7	-	56

Table 3

Results of *Cheilinus undulatus* survey in Raja Ampat Regency waters during 2012-2016

Date	Location	Distance (m)	Area (m^2)	Number C.undulatus	Estimated length (cm)	Fish per 10.000 m^2
			Meos Mansuar Sub-District[1]			
7-9 March 2012	Kri-Mansuar Island	22830.46	159813.25	52	10-40	3.25
10 March 2012	Kabui Bay	4881.37	34169.60	9	15-25	2.63
12 March 2012	Pianemo	1308.20	9157.41	1	15	1.09
		29020.04	203140.27	62		3.05
			Misool Sub-District[2]			
6 March 2013	Balbulol	6169.76	61697.62	20	7-60	3.24
6 March 2013	Campedak	2297.89	22978.87	4	30-35	1.74
7 March 2013	Namlol	6004.87	60048.65	18	12-30	3.00
8 March 2013	Harapan Jaya	4935.93	49359.31	9	20-30	1.82
9 March 2013	Wayaban	3514.65	35146.49	15	15-40	4.27
9 March 2013	Banyaganan	3192.78	31927.80	8	20-70	2.51
		26115.87	261158.74	74		2.83
			West Waigeo Sub-District[3]			
13 March 2013	Manyaifun	7857.44	62859.51	26	15-45	4.14
13 March 2013	Meos Manggara	3053.18	24425.45	7	10-20	2.87
14 March 2013	Bianci	5675.68	45405.45	12	10-25	2.64
15 March 2013	Mutus	2243.02	17944.19	3	15-25	1.67
		18829.32	150634.60	48		3.19
			Marine Protected Area of Ayau-Asia Islands[4]			
4 & 6 November 2015	Big Ayau (South)	4543.35	49976.84	30	15-70	6.00
5 November 2015	Big Ayau (North)	2512.47	27637.13	3	30-40	1.09
4-6 November 2015	Big Ayau (West)	5782.36	63605.97	17	15-60	2.67
6 November 2015	Big Ayau (East)	4791.15	52702.66	6	20-30	1.14
6 November 2015	Small Ayau (East)	1057.05	11627.51	4	10-25	3.44
7 November 2015	Small Ayau (North)	2155.85	23714.35	4	15-25	1.69
7 November 2015	Small Ayau (West)	1072.90	11801.86	4	25-35	3.39
7 November 2015	Small Ayau (South)	1129.28	12422.12	13	10-40	10.47
		23044.40	253488.44	81		3.20
			North Salawati Sub-District[5]			
09 August 2016	Jefman Island	3931	36367	7	20-40	1.92
10 August 2016	Wamega Village(North)	1361	20415	10	15-30	4.90
10 August 2016	Kasimraja Island	389	2723	1	35	3.67
11 August 2016	Matan Island	1153	17295	0	-	0.00
11 August 2016	Wamega Village (West)	1262	7885	38	5-35	48.19
		8096	84685	56		6.61

Source: [1]LPSPL Sorong (2012a); [2]LPSPL Sorong (2013a); [3]LPSPL Sorong (2013b); [4]LPSPL Sorong (2015); [5]Sombo (2017).

In order to figure out the most consistent number of *C. undulatus*, the survey track in North Salawati Sub-District is compared against fish abundance (Figure 3). Initially, its abundance was considerably low, and after 4-6 km elapsed, it is shown that abundance level was stable with approximately 3 individuals ha^{-1} (Figure 3). This condition is suggested to be realistic figure of the natural density in the area studied. However, it is far away from what it is called ideal density of 10 individuals ha^{-1} mentioned by Sadovy et al (2007).

Survey in *C. undulatus* abundance is important as prerequisite to quota allocation for catch and export. A more regular survey would be best practice, although it is costly and its feasibility would be once in 5 years (Sadovy et al 2007). Our combined data from both surveys during the last 5 years (2012-2016) showed that the cummulative abundance has been 3.36 individuals ha^{-1} with 105.105 km track length covering the area of 953107 m^2 where 321 tails of *C. undulatus* encountered. Based on Edrus (2012), this figure may categorized that the results of management measures has been able to improve *C. undulatus* population from vulnerable to recover (2.1-4.0 individuals ha^{-1}).

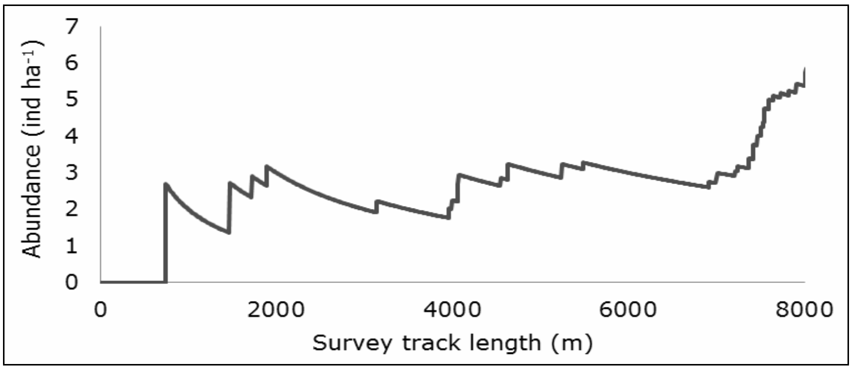

Figure 3. Abundance stability in *Cheilinus undulatus* along the track length in North Salawati Sub-District of Raja Ampat Regency waters.

Fish size distribution. The length of *C. undulatus* was dominated by juvenile and pre adult stages ranged between 5-40 cm in size (Table 3); this refers to Colin (2006) in which *C. undulatus* < 50 cm. In North Salawati Sub-District, *C. undulatus* size was largely ranged between 5-40 cm, where the dominant group was between 5-10 cm (Figure 4). This is to show that all fish are at juvenile phase of which it is commonly found < 50 cm in total length (Colin 2006). Such condition could indicate the event of sporadic recruitment pattern in high longevity fish such as *C. undulatus*, where population largely consists of young individuals (Gillet 2010).

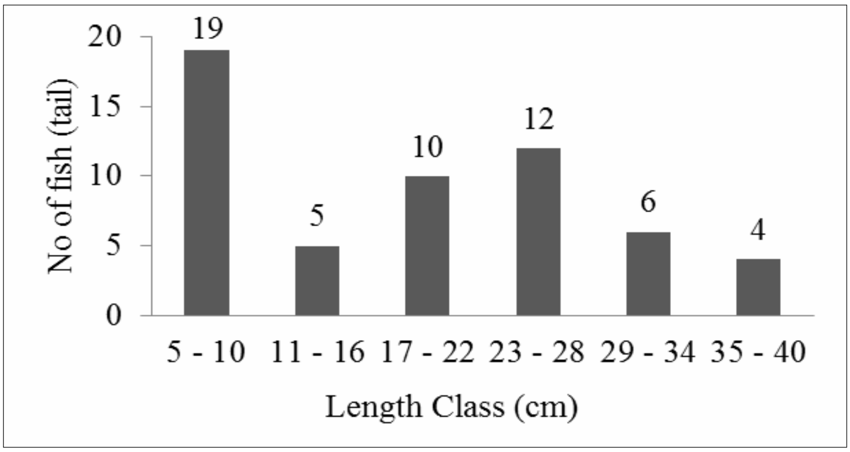

Figure 4. Size class distribution of *Cheilinus undulatus* in North Salawati Sub-District of Raja Ampat Regency waters.

Based on survey in 2013 and 2015, the bigger fish size up to 70 cm was found in Misool Sub-District and Ayau-Asia Islands. The latter location is the MPA area, suggesting that the current management measure, i.e. habitat protection resulted in better result.

Conclusions. The abundance in *C. undulatus* after surveyed using Underwater Visual Census (UVC) with Global Positioning System (GPS) method was varied between location and time as well as inside sub-location. The results has proven that the method is the best way to do in doing abundance survey for *C. undulatus*. The density in *C. undulatus* was moderately correlated with area rather than the distance. It is consistently shown that both previous and present results support to the fact that destructive fishing is the main cause to *C. undulatus* depletion in nature. Any management measures intended to protect fish and habitat support to the recovery of *C. undulatus* population. Based on size, the area studied is characterized by largely juvenile and pre-adult stages, indicating high vulnerability of any fishing activity as it would have been operated as juvenile fisheries.

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