Orientation Preference in Response to the Direction of Water Flow in 2 Species of Scallops with Different Shell Morphology

Rizky Darmawan[1,2] and Sonia Soltanizad[1,3]

[1] University of Washington, Seattle, WA 98195

[2] School of Aquatic and Fisheries Science, University of Washington, Seattle, WA 98195

[3] Department of Biology, University of Washington, Seattle, WA 98195

Contact Information

Sonia Soltanizad

Biology Department

University of Washington

313 padelford Hall

Seattle, WA 98195

ssoltanizad@hotmail.com

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Darmawan, Rizky and Soltanizad, Sonia

Abstract:

Scallops are marine bivalves that have a unique ability to swim and visualize their environment. Their eyes allow them to detect light and moving particles. It also gives them the ability to sense their surroundings and look for more suitable locations. In addition, the animals change their orientation position with water flow in order to maximize their food intake and growth. Both Chlamys rubida and Chlamys hastata exhibit these abilities, despite their morphological and behavioral differences. However, because of their profound distinctions that separate them between species, we suspect that the two groups will exhibit differences in their orientation preference to the current. Orientation position will optimize growth and feeding for these species within their local environment. Our hypothesis on scallops' orientation was tested in a flume tank. Their angle in respect to the water flow were measured and recorded for comparison. The experiment demonstrated that there was no statistical difference in orientation preference between the two species in a well-lit environment, and that their vision had no considerable influence on their orientation. However, we were able to find a statistical difference in how the two species preferred to orient themselves within a dark environment.

Introduction:

Scallops are marine bivalves that feed on small-suspended particles and algae. They are dependent on water movement to bring food within reach (Cahalan et al. 1989). Scallops have a unique ability to swim using jet propulsion (Moore & Trueman 1971). They create the jet propulsion by clapping their shell quickly, creating a water jet behind them. The direction of swimming is not random. An experiment done in 1985 by Winter and Hamilton proved that scallops could direct their movement depending on the situation. They do this be modifying their mantle (Stanley 1970), and by so, controlling the direction of the jet propulsion. Using this ability, scallops can escape predation and move to a more suitable place.

Another unique feature of scallops' is that they're visual animal. They have well-developed eyes that could detect light and moving particles (Speiser & Johnsen 2008). Scallops comprise a numerous number of eyes, and have them all positioned surrounding the outer part of their mantle. A scallop's eye is able to concentrate high measures of light onto each retina, making them extremely efficient in sensing light and movement (Colicchia et al. 2009). With these well-developed eyes, they are able to visually select locations with larger food particles, in addition to being able to detect current speed and flow direction of their surroundings (Speiser & Johnsen 2008). The study conducted by Eckman et al. (1989) suggested that adult scallops' growth are sensitive to current speed. Also, in order for them to maximize their food intake, scallops must orient themselves accordingly to the water flow (Sakurai & Seto 2000).

The *Chlamys rubida* & *Chlamys hastata* are two species of scallops that is commonly found on the Northern Pacific (Bernard 1983). However, although they belong in the same genus, they are separated by their distinctive differences in shell morphology. The shell of the *C. rubida* is more circular and has between 20-30 prominent ribs on both of its valves, which lack both spines and ruffles (Kozloff 1993). On the other hand, the left valve of the *C. hastata*'s shell has ribs with very pronounced spines and ruffles. Correspondingly, the difference in shell morphology is the most notable character in distinguishing the two species from one another, and may have a substantial correlation in their behavioral responses in facing fluid dynamics and orientation preference (Gruffyd 1976; Winter & Hamilton 1985).

Both species of scallops generally coexist in the same geographical proximity on the Northern Pacific coast, ranging from the Gulf of Alaska to southern California (MacDonald et al. 1991). *C. hastata* are commonly found sub-tidally from 16-492ft, while *C. rubida* can be found up to 656ft. *C. rubida* also favors soft surfaces that are either sandy or muddy, opposite to *C. hastata*, who would rather have a more firm gravel or rocky surface (Bernard 1983). However, both species do opt for locations where they would experience some degree of water flow.

Studies on *C. hastata* and *C. rubida* orientation are important not only to assemble fundamental ecological and ethological knowledge, but also because scallops are commercially relevant species. The more we understand what influences their behavior and feeding, the more helpful it will be in culturing and growing them in captivity. Fluid conditions influence scallop juvenile growth (Eckman et al. 1989), and orientation response is an important measure of how the animals optimize feeding in their local environment. Also, considering that these two species are clearly different, and yet continue to co-occur with one another, it is entirely possible that one species is more sensitive to environmental change than the other. Therefore, it is important to compare preferences to stimuli that optimize growth between the two species, such as orientation. Additionally, it could be used to form precautionary measures in preserving their coexistence for the future.

This experiment will test whether there is a difference in orientation preferences between the two species in response to water flow. Also, the scallops will be tested in a dark environment to see whether it will affect how they orient themselves in flowing water. Testing in a dark environment will rule out the effect of vision on scallop orientation. Presuming that swimming scallops such as *the C. hastata* and *C. rubida* are able to visually select more suitable habitats (Speiser & Johnsen 2008), there is a substantial probability that their orientation to the current in the presence of light will differ from their orientation in a darkened environment. Therefore, by testing in the dark, the two species will less likely be able to orient themselves to the current based on more favorable feeding conditions, but respond to physical cues even in the absence of visual cues and their ability in facing the fluid conditions. It is expected that there will be a difference in the orientation preference between the *C. hastata* and *C. rubida*. Also, it is expected that the scallops tested in the dark will react slower than in a well-lit room.

Materials and Methods:

Forty specimens of each of the two local west-coast scallop species, *C. rubida* and *C. hastata*, were used in this experiment. Specimens were collected from Argyle Creek, San Juan Island, Washington, and by otter trawl from 70m depth at San Juan Channel, San Juan Island (RV Centennial). The two species were distinguished by, the number of counted radial ribs of their left valve. To make each measurement, we labeled and photographed each scallop next to a ruler with the left valve upright. Prior to labeling each individual with unique identification number, all the encrusting barnacles or other epifauna on the scallop's shell surfaces were removed. Barnacle encrustations intensify the drag coefficients experienced by swimming scallops, and therefore might have a negative affect in their ability to move by increasing the energy needed to do so (Donovon et al. 2003).

Before the first experiment was conducted, all specimens were acclimated in a collective indoor holding tank filled with seawater that was approximately between 10-12 degrees. This way, they all shared similar conditions of water temperature, lighting, and interactions with other species.

For all the experiments, the scallops were tested in the same closed flume tank. To fill the tank with seawater, we had to place a hose that had one end connected to receiving ocean seawater into the flume tank. Water temperature was measured at the start and again at the end of each trial over the thirty minute time period. After each trial was completed, the flume tank had to be drained of the seawater, cleaned out with the freshwater hose, and then again filled with seawater for next trial.

Our experiments consisted of four alternating treatments, two in the light and two in the dark. In between each treatment, the animals were acclimated to their new condition for twenty-fours\ hours prior of the next treatment.

For each trial, we randomly selected five scallops from the holding tank containing both species. After selection, the starting orientation (the ventral edge facing toward or away from the flow) for the group was determined by a coin flip. Trials lasted for a set time of 30 minutes. We recorded measurements of each individual's orientation at the start (pre-determined), at 15 minutes (half-way point) and at the end. To measure each scallop's orientation angle at the two checkpoints, we placed a protractor facing perpendicular to the flow at 0 degrees upstream, directly above specimen and photographed it. After all eighty scallops completed a trial; they began their 24 hours acclimation period leading to their next treatment. Additionally, we re-used all 80 specimens for the four treatments

Data analysis

In order to analyze scallops' orientation in response to the current, we had to statistically compare orientation angles between species in different treatments. We used Mann-Whitney U statistics to compare orientation in light and dark treatments between the two groups. Additionally, using the same statistical test we compared orientation between light and dark conditions within the same species.

Result:

Measurement:

C. rubida had an average length of 4.21cm with a standard Deviation 0.846. (Table.1)

C. hastata had an average length of 4.36cm with a standard deviation 0.998. (Table.2)

Pilot trial:

In our pilot trials, we tested five scallops from each of the two species in the flume tank in a lighted environment. We observed they're reactions to the flowing water current at speeds of 5cm/s, 10cm/s and 20cm/s. We noticed that on average both species began to quickly alter their orientations to the current and that they continued to make adjustments as the trial continued. Therefore, we determined that 30 minutes is an adequate amount of time to run each test, along with recorded observations done at the initial starting point, the 15-minute half-way point, and at the final 30 minute mark. Also, we saw that the scallops will be dislodged at 15cm/s and 20cm/s, so we decided to do the experiment in 7cm/s. Data were accumulated from each individual scallop within every trial. We used this same experimental design to test scallops' behavior in the dark.

Data Analysis:

We recorded our trials in tables (Table.3;Table.4;Table.5;Table.6). Then we separated the raw data into bins and made a figure to see any trend in the result. Our first results conducted from our main experiment comparing orientation between C. hastata and *C. rubida* in a lighted condition showed no statistically significant difference (Figure.1;Figure.2;P-value: 0.332) in orientation preference between the two species

(Table.3). However, our following results testing orientation between the two species in the dark showed that there was indeed a statistical difference in how the two different species orient themselves in the dark (Figure.3;Figure.4;P-value: 0.0042). Furthermore, there was no significant difference in how either group of species oriented themselves in the light or in the dark (*C. hastata* P-value: 0.550 ; *P. rubida* P value: 0.183).

Discussion:

We found that *C. rubida* show a preference in 75-105 degree angle (Figure.1) while the *C. hastata*'s preference is more random (Figure.2). However, the statistical test shows no significant difference in the orientation preference of *C. hastata* and *C. rubida* in a well-lit environment (P-value: 0.332). Orientation preference between the two species also may be completely at random. However, Japanese scallops *Patinopecten yessoensis* orient their ventral edge upstream in trials of up to 60 minutes (Sakurai & Seto 2000). It is possible that the *Chlamys* spp. in our experiment did not have sufficient time to orient themselves. Alternatively, our specimens may have been under a great deal of stress after being captured and removed from their natural habitat. For those reasons, if the specimens were given more time or if they had been observed within a more natural environment, they would then exhibit statistically different orientation preferences. Another factor that might have stressed the scallops was transporting it between the labs. The scallops might experience some turbulence while it is being transported due to human intervention.

We speculated that the two species could have different orientation preferences under suitable conditions because of their obviously different shell features. The most noticeable feature distinguishing the two closely related *Chlamys* spp. is their shell morphologies (Kozloff 1993). Because there is this profound morphological distinction between the two, we suspected it may affect their orientation in relation to the principles of fluid dynamics (Gruffyd 1976). Future work could test this hypothesis by directly testing the effect of shell morphology on orientation within each species, for example by attaching extra ridges on *C. rubida* and by infilling the valleys between the ridges on *C. hastata*, and repeating our present experimental design. Another interesting experiment that could be done is by filling the ridges of the *Chlamys* spp., smoothing them up, and observing them using the same method as this experiment.

There is no analytical difference in how either *C. hastata* or *C. rubida* orients in the light and dark. A scallop eye can detect light and moving particles (Speiser & Johnsen 2008), but past research on *Argopecten irradians* filtration showed that there was no significant difference in filtration rates between light and dark periods (Palmer 1980). This latter point corresponds with our observation of no difference in orientation in the light and dark in *Chlamys* spp. Some reasons that might explain this is because scallops move less in the dark. The 15 and 30 minute data shows that the scallops tend to move less in the dark. The scallop might do their orientation at daytime and keep their orientation throughout the night. By doing that, the scallops will reduce their chance on being detected by their predators. Furthermore, both *C. hastata* and *C. rubida* are filter feeders and prefer to orient themselves to the current in a way that will optimize their feeding (Sakurai & Seto 2000). This is the fundamental supporting factor we believe underpins the finding that there was no statistical difference within each species orientation in the light and at dark: because they were able to filtrate at the same rate in either condition.

We found a significant difference in how the two *Chlamys* spp. orient themselves to the current in a dark environment. The importance of finding a statistically significant difference (P-value: 0.0042) between the two species orientation preference in dark conditions, is because it could explain how the two scallops co-occur within the same environment but have preferred habitats within this region (Bernard 1983). This difference could be due to the species having distinct habitat preferences within their shared region (Bernard 1983). Additionally, the animals may experience a circadian rhythm, which has been observed in a tremendous number of multi- and unicellular organisms, including invertebrates (Rosbash 1995). Therefore, the scallops' orientation may be connected to the time of day, which also connects with the oceans tides. The speed of the oceans's current are primarily linked to the tidal cycle, which is controlled by the moon

If given the opportunity to reattempt our experiment, a change that we would make that we believed could have had a significant effect on the data, is to test each scallop individually in the flume tank for thirty, instead of in groups of five. This way there would be more room availability and any influence that the scallops might have had on one another would be eliminated. Also, we would change the experimental design to 60 minutes instead of 30 minutes according to the experiment done by Sakurai & Seto (2000). Because although our data did not allow us to accept our hypothesis of the two closely related species of *Chlamys* spp. having different orientation preference to the current, we still believe based on other studies that there is orientation preference between the two, considering it being a stimulus that optimize growth for them both (Eckman et al. 1989).

In conclusion, the experiment proves that our previously stated hypothesis is incorrect except for their orientation in the dark. Our experiment proves that there is no orientation preference between the two *Chlamys* spp. at day time. However, the dark experiment suggests that there is a statistically significant difference between the *Chlamys* spp. at night time. Also, the two scallops did not show any change in their orientation preference between day and night time. However, evidence from other researches suggests that there is a difference between the two. Therefore, similar experiment with modified methods could be done to further investigate this.

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Table and Figures

Table.1 ***C. rubida measurements***

Number	Length (cm)	Ruffles
1	3.4	30
2	4.5	28
3	3.4	28
4	5.8	25
5	3.8	30
6	4.1	27
7	5.2	23
8	2.9	36
9	4.2	34
10	4.4	32
11	3	28
12	4.7	27
13	5.5	28
14	3.4	27
15	4.2	24
16	5.3	35
17	5	29
18	4.4	23

19	4.5	26
20	4.4	23
21	4.3	26
22	3.6	28
23	3.5	29
24	3.6	27
25	4.3	32
26	2.7	26
27	3	30
28	4.4	30
29	5.9	34
30	3.6	32
31	3.4	23
32	4.6	27
33	4.6	25
34	2.7	23
35	4.7	27
36	4.7	21
37	3.3	24
38	5.3	30
39	5.4	32
40	4.8	31
Mean	4.2125	28

Standard Deviation	0.846	3.612

Table.2 *C. hastata* measurements

Number	Length (cm)	Ruffles
1	4	9
2	4.1	7
3	4.3	9
4	4.9	3
5	4.6	6
6	5	5
7	5.1	5
8	4.8	3
9	4.6	3
10	5.2	6
11	4	5
12	6	4
13	5.3	4
14	5	5
15	4.6	3
16	5.1	17
17	5.7	5
18	5.7	6
19	5.1	9
20	3.7	4

21	5.4	7
22	5.2	3
23	6.1	5
24	5.4	4
25	3.4	4
26	3.2	3
27	3.7	3
28	3.3	3
29	3.2	4
30	3.6	4
31	3.8	7
32	3.1	7
33	4.1	3
34	2.9	3
35	2.7	4
36	5.1	8
37	2.5	3
38	3.1	5
39	2.5	6
40	5.1	3
Mean	4.355	5.175
Standard Deviation	0.998	2.626

Table.3 Day 1 Trial

Specimen	Species	Direction @ 15	Direction @ 30
1	*hastata*	109	94
2	*hastata*	2	10
3	*hastata*	158	161
4	*hastata*	174	179
5	*hastata*	155	158
6	*hastata*	8	5
7	*hastata*	116	124
8	*hastata*	11	90
9	*hastata*	68	50
10	*hastata*	60	68
11	*hastata*	46	59
12	*hastata*	118	75
13	*hastata*	164	177
14	*hastata*	140	118
15	*hastata*	106	59
16	*hastata*	153	152
17	*hastata*	96	91
18	*hastata*	70	11
19	*hastata*	90	175

20	*hastata*	65	90
21	*hastata*	180	179
22	*hastata*	27	120
23	*hastata*	180	180
24	*hastata*	168	158
25	*hastata*	142	159
26	*hastata*	10	118
27	*hastata*	0	15
28	*hastata*	180	180
29	*hastata*	109	112
30	*hastata*	56	113
31	*hastata*	47	161
32	*hastata*	26	90
33	*hastata*	27	134
34	*hastata*	139	89
35	*hastata*	136	72
36	*hastata*	135	135
37	*hastata*	172	104
38	*hastata*	161	160
39	*hastata*	30	57
40	*hastata*	108	85
1	*rubida*	135	124
2	*rubida*	173	175

3	*rubida*	140	74
4	*rubida*	97	93
5	*rubida*	136	87
6	*rubida*	34	63
7	*rubida*	104	156
8	*rubida*	44	120
9	*rubida*	159	92
10	*rubida*	164	167
11	*rubida*	100	41
12	*rubida*	135	90
13	*rubida*	7	69
14	*rubida*	106	135
15	*rubida*	180	94
16	*rubida*	112	117
17	*rubida*	76	78
18	*rubida*	102	86
19	*rubida*	85	98
20	*rubida*	105	103
21	*rubida*	136	157
22	*rubida*	92	180
23	*rubida*	12	96
24	*rubida*	91	112
25	*rubida*	79	73

26	*rubida*	88	80
27	*rubida*	173	142
28	*rubida*	178	51
29	*rubida*	136	63
30	*rubida*	102	42
31	*rubida*	178	177
32	*rubida*	172	170
33	*rubida*	1	11
34	*rubida*	46	109
35	*rubida*	90	91
36	*rubida*	83	86
37	*rubida*	61	104
38	*rubida*	156	179
39	*rubida*	166	176
40	*rubida*	134	102

Table.4 Day 2 trial

Specimen	Species	Direction @ 15	Direction @ 30
1	*hastata*	139	113
2	*hastata*	116	150
3	*hastata*	32	101
4	*hastata*	114	74
5	*hastata*	155	152
6	*hastata*	79	129
7	*hastata*	121	159
8	*hastata*	69	74
9	*hastata*	13	6
10	*hastata*	10	23
11	*hastata*	28	17
12	*hastata*	178	156
13	*hastata*	27	28
14	*hastata*	99	112
15	*hastata*	46	178
16	*hastata*	158	116
17	*hastata*	24	68
18	*hastata*	74	69
19	*hastata*	60	91

20	*hastata*	160	169
21	*hastata*	180	180
22	*hastata*	1	21
23	*hastata*	180	180
24	*hastata*	111	109
25	*hastata*	174	158
26	*hastata*	72	61
27	*hastata*	0	24
28	*hastata*	49	66
29	*hastata*	135	136
30	*hastata*	85	29
31	*hastata*	1	110
32	*hastata*	152	162
33	*hastata*	115	151
34	*hastata*	173	177
35	*hastata*	89	33
36	*hastata*	10	22
37	*hastata*	148	148
38	*hastata*	12	21
39	*hastata*	102	103
40	*hastata*	179	156
1	*rubida*	59	1
2	*rubida*	180	180

3	*rubida*	156	139
4	*rubida*	92	90
5	*rubida*	11	9
6	*rubida*	169	92
7	*rubida*	129	135
8	*rubida*	100	102
9	*rubida*	148	16
10	*rubida*	180	170
11	*rubida*	112	45
12	*rubida*	75	88
13	*rubida*	79	91
14	*rubida*	142	110
15	*rubida*	2	9
16	*rubida*	81	134
17	*rubida*	105	139
18	*rubida*	112	134
19	*rubida*	154	134
20	*rubida*	180	180
21	*rubida*	131	132
22	*rubida*	108	116
23	*rubida*	160	176
24	*rubida*	28	46
25	*rubida*	155	128

26	*rubida*	0	0
27	*rubida*	108	38
28	*rubida*	161	86
29	*rubida*	171	92
30	*rubida*	15	0
31	*rubida*	152	121
32	*rubida*	90	102
33	*rubida*	171	27
34	*rubida*	12	9
35	*rubida*	26	0
36	*rubida*	101	69
37	*rubida*	54	63
38	*rubida*	158	82
39	*rubida*	172	180
40	*rubida*	102	63

Table.5 Night 1 trial

Specimen	Species	Direction @ 15	Direction @ 30
1	*hastata*	10	15
2	*hastata*	96	135
3	*hastata*	175	178
4	*hastata*	15	15
5	*hastata*	95	115
6	*hastata*	0	13
7	*hastata*	93	90
8	*hastata*	124	165
9	*hastata*	94	170
10	*hastata*	4	17
11	*hastata*	95	95
12	*hastata*	15	10
13	*hastata*	130	130
14	*hastata*	120	160
15	*hastata*	60	102
16	*hastata*	105	105
17	*hastata*	133	135
18	*hastata*	27	15
19	*hastata*	170	115

20	*hastata*	173	175
21	*hastata*	180	177
22	*hastata*	180	175
23	*hastata*	0	0
24	*hastata*	140	117
25	*hastata*	120	180
26	*hastata*	74	92
27	*hastata*	115	108
28	*hastata*	170	174
29	*hastata*	155	160
30	*hastata*	120	120
31	*hastata*	153	155
32	*hastata*	35	120
33	*hastata*	173	173
34	*hastata*	125	125
35	*hastata*	25	25
36	*hastata*	158	160
37	*hastata*	175	175
38	*hastata*	12	90
39	*hastata*	123	122
40	*hastata*	150	150
1	*rubida*	31	10
2	*rubida*	74	55

3	*rubida*	0	0
4	*rubida*	10	15
5	*rubida*	0	0
6	*rubida*	86	150
7	*rubida*	45	68
8	*rubida*	50	97
9	*rubida*	97	97
10	*rubida*	180	180
11	*rubida*	54	50
12	*rubida*	45	85
13	*rubida*	13	15
14	*rubida*	45	180
15	*rubida*	23	20
16	*rubida*	120	120
17	*rubida*	0	0
18	*rubida*	10	10
19	*rubida*	3	150
20	*rubida*	170	175
21	*rubida*	170	172
22	*rubida*	180	151
23	*rubida*	0	165
24	*rubida*	12	11
25	*rubida*	80	120

26	*rubida*	98	100
27	*rubida*	115	93
28	*rubida*	13	48
29	*rubida*	180	180
30	*rubida*	50	50
31	*rubida*	105	12
32	*rubida*	112	73
33	*rubida*	121	121
34	*rubida*	85	50
35	*rubida*	24	23
36	*rubida*	0	10
37	*rubida*	5	5
38	*rubida*	117	117
39	*rubida*	0	35
40	*rubida*	93	87

Table.6 Night 2 trial

Specimen	Species	Direction @ 15	Direction @ 30
1	*hastata*	178	151
2	*hastata*	122	118
3	*hastata*	33	121
4	*hastata*	96	168
5	*hastata*	142	119
6	*hastata*	170	114
7	*hastata*	111	75
8	*hastata*	96	114
9	*hastata*	178	176
10	*hastata*	179	180
11	*hastata*	116	95
12	*hastata*	173	179
13	*hastata*	0	0
14	*hastata*	11	16
15	*hastata*	45	83
16	*hastata*	2	12
17	*hastata*	156	161
18	*hastata*	122	121
19	*hastata*	169	173

20	*hastata*	174	177
21	*hastata*	0	1
22	*hastata*	17	8
23	*hastata*	120	180
24	*hastata*	22	20
25	*hastata*	13	50
26	*hastata*	0	36
27	*hastata*	153	156
28	*hastata*	154	158
29	*hastata*	27	13
30	*hastata*	82	122
31	*hastata*	73	57
32	*hastata*	52	48
33	*hastata*	50	99
34	*hastata*	12	92
35	*hastata*	45	180
36	*hastata*	180	180
37	*hastata*	134	137
38	*hastata*	180	175
39	*hastata*	12	10
40	*hastata*	152	151
1	*rubida*	3	150
2	*rubida*	0	11

3	*rubida*	116	108
4	*rubida*	95	97
5	*rubida*	0	2
6	*rubida*	116	118
7	*rubida*	99	100
8	*rubida*	12	9
9	*rubida*	97	136
10	*rubida*	45	66
11	*rubida*	104	103
12	*rubida*	23	24
13	*rubida*	95	85
14	*rubida*	118	122
15	*rubida*	174	174
16	*rubida*	129	132
17	*rubida*	169	172
18	*rubida*	24	22
19	*rubida*	127	126
20	*rubida*	126	167
21	*rubida*	12	17
22	*rubida*	3	15
23	*rubida*	54	48
24	*rubida*	103	13
25	*rubida*	11	16

26	*rubida*	175	173
27	*rubida*	85	50
28	*rubida*	82	40
29	*rubida*	6	4
30	*rubida*	29	10
31	*rubida*	95	97
32	*rubida*	124	123
33	*rubida*	4	165
34	*rubida*	74	90
35	*rubida*	86	151
36	*rubida*	93	88
37	*rubida*	120	162
38	*rubida*	168	173
39	*rubida*	61	100
40	*rubida*	2	0

Figure.1

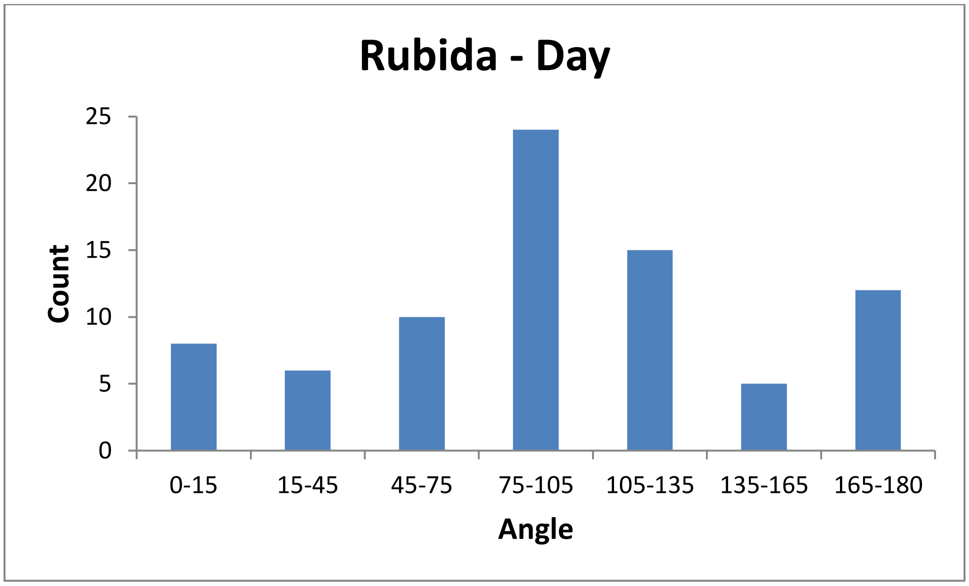
Rubida - Day
Count
25
20
15
10
5
0
0-15
15-45
45-75
75-105
105-135
135-165
165-180
Angle

Figure.2

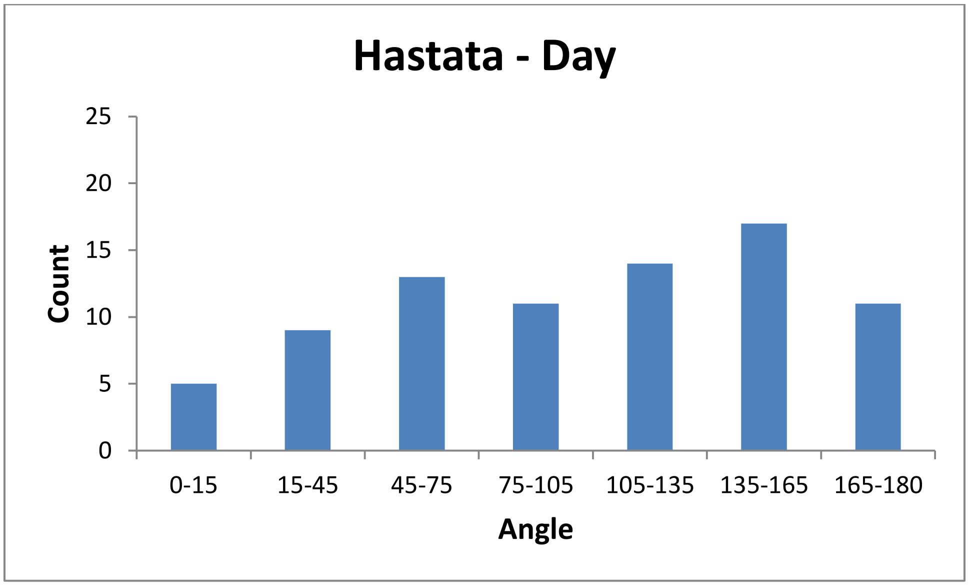
Hastata - Day
Count
25
20
15
10
5
0
0-15
15-45
45-75
75-105
105-135
135-165
165-180
Angle

Figure.3

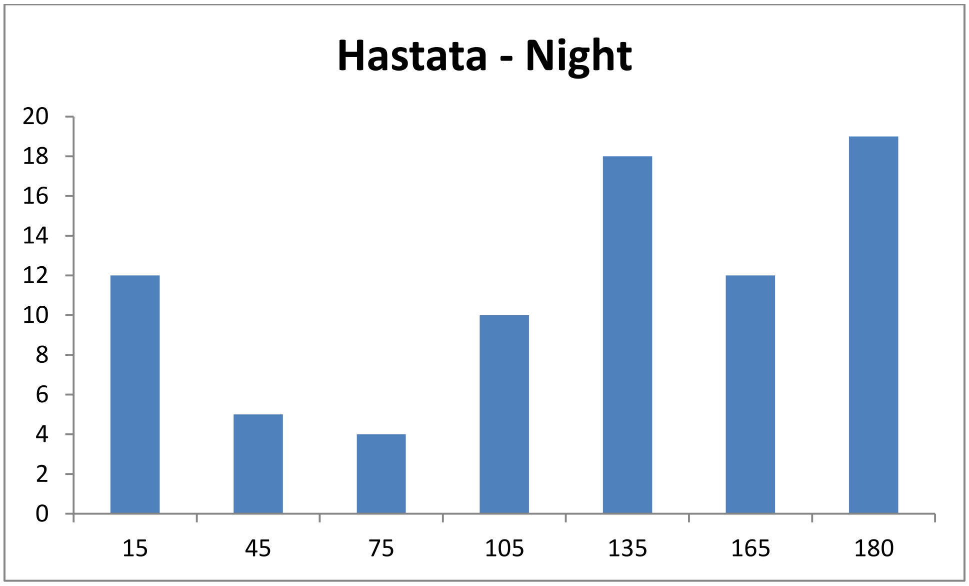

Figure.4