Modelling Uncertainty in the Search for HMAS Sydney

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ABSTRACT

The loss of the cruiser HMAS Sydney to the German raider HSK Kormoran is Australia's worst naval disaster. Since her loss on the 19th of November 1941 the location of Sydney's wreck has been a mystery. Many researchers have defined possible locations for Sydney and Kormoran. However, none have used the available evidence in a rigorous mathematical manner that considered the uncertainty in each of the items of evidence used to obtain the position. Few of them have considered all of the available evidence objectively and without ignoring evidence that contradicts their hypothesis. This project uses a least squares based approach to solve for the probable location of both ships. The search areas are defined using the associated area of confidence for each of the solutions. The network adjustments have been performed several times to accommodate different sets of data where various options exist for the use of the available information. The application of survey network theory to marine archaeology is shown to be sound, however additional information and modelling could provide a more definitive solution.

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INTRODUCTION

The loss of the Australian cruiser HMAS *Sydney* to the German raider HSK *Kormoran* is Australia's worst naval disaster. The *Sydney* went down with all hands (645 men and officers) on the 19th of November 1941.

On the 11th of November 1941, HMAS *Sydney*, under the command of Captain Joseph Burnett, left Fremantle on escort duty with Hired Transport *Zealandia* to the Sundra Strait. After handing her charge over to HMS *Durban* on the 17th of November, *Sydney* sailed for Fremantle. At about 4pm on the 19th of November, while in the vicinity of 26° S 111°E, *Sydney* intercepted the German armed merchant cruiser (raider) *Kormoran*, disguised as the Dutch *Straat Malakka* and commanded by Captain Theodor Detmers. In the ensuing battle *Sydney* was heavily damaged with the bridge destroyed and the fire control system disabled early in the battle. *Kormoran* was crippled by a hit to her engine room and was scuttled by her crew later that night. *Sydney* was last seen drifting away, burning amidships and astern.

A few days after *Sydney* was expected to reach Fremantle the authorities attempted to contact her. Search aircraft were despatched on the 24th of November. The searches failed to find any of the *Sydney's* crew, however most of the crew of the *Kormoran* were rescued. Much of the evidence regarding the loss of the ships has come from survivors and the search and rescue operations.

Since the battle many have argued over how *Kormoran* could have vanquished a heavily armed and battle-hardened cruiser and why there were no Australian survivors. Contradictory evidence, government secrecy, inconsistent government reports and other influences have fuelled the arguments. Michael Montgomery's controversial, and since discredited (Winter, 1984), book *Who Sank the Sydney?* inflamed the debate with it's accusations of war crimes and the involvement of a Japanese submarine. Despite searches by the Royal Australian Navy and other interested parties neither the wreck of *Sydney* nor *Kormoran* has been found. Some researchers believe that if *Sydney* were found she could be examined and perhaps the circumstances of her demise could be reconstructed.

In 1997 a Joint Standing Committee on Foreign Affairs, Defence and Trade held the *Parliamentary Inquiry into the Circumstances of the Sinking of HMAS Sydney*. The parliamentary inquiry was the largest in Australia's history receiving submissions from over 200 interested parties plus many supplementary submissions totalling nearly five-thousand pages. A number of the submissions hypothesized on what happened on the night of the 19th of November 1941 in an attempt to explain the loss of Sydney and her entire complement and to define locations for the wrecks.

Evidence regarding the loss of the two ships exists in a number of forms: information given by the German survivors, objects found during the search and rescue operations and oral histories from people along the Western Australian coast. Much of this evidence appears contradictory or internally inconsistent. Previously only Kirsner (1991), Hughes (1991) and Kirsner & Hughes (1993) have used the historical evidence in a purely objective way (i.e. without sampling the available evidence to suit a preconceived hypothesis). However, the uncertainty contained in each item of evidence (eg from memory loss, imprecise meteorological data) was not fully accounted for. This paper presents the available evidence that may be used to determine the resting place of both ships in terms of measurements and attempts to quantify the uncertainty in the evidence using precisions. The precisions given in this paper as given at one-sigma (39%) level unless otherwise specified. These measurements are then composed into a number of networks and adjusted using survey network theory based on the least squares algorithm. The main aim of this project is to investigate the use of survey networks in the context of locating shipwrecks.

PHYSICAL AND ORAL EVIDENCE

Drift Items

A variety of physical evidence resulting from the losses of *Sydney* and *Kormoran* were found during the search for survivors. The most notable of these were the lifeboats containing the German survivors. For each item recovered, the time and position was collected. All of these observations must be corrected for drift to backplot them to their position of origin. However, not all of these are suitable for drift analysis for a variety of reasons. For example, the potential for sail driven movement cannot be discounted on some lifeboats. A diary kept by the German Lieutenant von Malapert allows the sailing vectors of Kohn and Meyer's lifeboats to be calculated. Table 1 records those drift items that have been deemed suitable for drift analysis. The precisions have been estimated based on the navigation instruments and practiced by the recovery vessel.

Table 1: Positions of Debris

Name	Position from Search and Rescue	Precision Nm	Source Vessel	Source
Carley Float	24° 07' S 110° 58' E	2	HMAS *Sydney*	Hardstaff, 1997
Float	24° 10' S 110° 54' E	7	HSK *Kormoran*	Winter, 1984
Green Box	24° 10' S 110° 54' E	7	HSK *Kormoran*	Winter, 1984
Kohn's Lifeboat	24° 10' S 113° 27' E	2	HSK *Kormoran*	Winter, 1984
Lifebelt A	24° 22' S 110° 49' E	2	HMAS *Sydney*	Winter, 1984
Lifebelt B	24° 06' S 110° 49' E	10	HMAS *Sydney*	Hardstaff, 1997
Lifebelt C	24° 10' S 110° 54' E	7	HSK *Kormoran*	Winter, 1984
Meyer's Lifeboat	24° 03' S 113° 26' E	2	HSK *Kormoran*	Winter, 1984

Reports by Survivors

Various crewmembers from the *Kormoran* have provided positions for the battle. These are shown in Table 2. Also included is part of a distress signal received by Geraldton radio, unintelligible except for "2 (gap) 7 C 111 15 E 1000 GMT" (Frame, 1998). Detmers sent the distress call with the intention of confusing and distracting *Sydney* (Detmers, 1959). It is unlikely that Detmers would have transmitted a false coordinate in the signal, as this would have aroused suspicions onboard *Sydney*. Making the assumption that the 'C' was misheard and was actually a 'S' the longitude component of message received by Geraldton radio can be used as a position measurement. A ship such as *Sydney* or *Kormoran* would have been using a sextant, chronometer, gyrocompass and a log to determine their position to an accuracy of one nautical mile or better (McDonald, pers com, 1999a). However, Linke and Pachmann, two wireless operators from the *Kormoran*, give the position only to the nearest degree. Given this and the garbled nature of the signal, the longitude part of this signal has been assigned a precision of 15 nautical miles.

Many of the German survivors provided position estimates during the interrogations. A number of these sailors would not be in a position to have direct access to navigation information as part of their duties. Also, according to Frame (1998) the interrogations revealed that Detmers kept his subordinates ill-informed about the ship's activities. Officers were seldom allowed into the chartroom, and during the night watch only the Navigating Officer (Meyer) determined the ship's position. Knowing this one could assume that the positions given by Detmers and Meyer are more likely to be accurate than the others. However, there was ample opportunity before and between the interrogations for the officers to pass on information false or otherwise to the crew. Given these considerations, it is difficult to determine the ultimate source of the information provided by the crewmembers. It must be assumed that only those officers and men with access to navigational information could provide a reliable estimate of the position of the battle and that all other positions must be derived from these or be misinformation. If positions that are derived or quoted from positions given by others are included into the least squares algorithm they will add undue weight to those measurements. In addition the measurements will be highly correlated and bias the results. Table 2 records the positions given by sources that are likely to have had access to the information.

Table 2: Position Measurements

Name	Location	Precision (nm)	Source Vessel	Source
Bretschneider's Position	26° S 111° E	20	HSK *Kormoran*	NAA MP1587/1 165K
Detmers' Position	26° 32' S 111° 0' E	15	HSK *Kormoran*	Winter, 1984
Meyer's Position	27° S 111° E	20	HSK *Kormoran*	Olson, 2000
Pachmann's Position	26° S 111° E	20	HSK *Kormoran*	Olson, 2000
Linke's Position	26° S 111° E	20	HSK *Kormoran*	Olson, 2000
Geraldton Radio	111° 15' E	5	HSK *Kormoran*	Hardstaff, 1997

It is reasonable to expect the German officers and men would try and hamper the efforts of the enemy by giving misinformation. There are two main arguments concerning this. The first is that, as there was no doubt that the *Kormoran* was sunk and the *Sydney* was last seen afloat and under power they may have not seen any reason to give false information about the location of the battle (Winter, 1984). The second argument is that Detmers used illegal tactics to overcome *Sydney* and deliberately gave a position in deep water in order to discourage the Australian authorities from investigating the wreck (Montgomery, 1981). The truth in this matter may never be known. It is important to note that if these positions are false or contain a gross error (eg. if the Germans gave misinformation) then they will bias the algorithm. To overcome this a number of sets of measurements are used to test the agreement between the various sources of information.

Some consideration must be given to all the positions for failures in memory as the crew was rescued some six days after the event and not interrogated until some time afterwards. To complicate matters many of the numerous signals, reports and interrogation notes in the archives contain typographical, rounding and other errors and often do not reference the source of the original material. For the above reasons the reliability of all of the positions are going to be significantly worse than one mile. Just how unreliable the information the Germans gave is very difficult to quantify. Precisions have been estimated based on the reliability of the source and the rounding of coordinates.

Relative Positions

The last measurement taken by a range finder gave the distance from *Kormoran* to *Sydney* as 16,000m (NAA: B5823, Whole Series). The *Sydney's* course was estimated at about 150° and the relative bearing between the ships at the time of the last shots was 225°. However, the glow of flames was seen for at least four hours after the battle ceased. The Australian interrogator, Lieutenant-Commander Rycroft, after interviewing Captain Detmers and First Officer Foerster arrived at the conclusion that *Sydney* was on a bearing of 153° heading south at about 5 knots (Winter, 1984). Just how far *Sydney* may have drifted is a matter of conjecture. If *Sydney* managed to maintain the five knots for about four hours (which is at least how long survivors saw a glow) she would have travelled about twenty nautical miles. To reflect this, a distance of 30nm has been used with an extremely high standard deviation of 20nm (as there is no certainty as to how long *Sydney* was afloat or what average speed she maintained before sinking). The bearing between *Kormoran* and *Sydney* has been set at 153° with a standard deviation of 20°. This standard deviation reflects the fact *Sydney* may have changed course, perhaps by heading towards Geraldton or Port Gregory. However, given the heavy damage sustained by *Sydney*, including the loss of the bridge, it seems unlikely that she was navigable.

The QQQ message received by Geraldton radio was also intercepted by the tug *Uco* in position at 26° 45' S 113° 20' E (Olson, 2000). The message was garbled and the position given unclear. However, the radio operator estimated, presumably by the signal strength, that the transmitting vessel was within 300 miles. This measurement would best be handled as a constraint within the least squares adjustment. However, constraints of this nature are not often used in surveying and the software used in this research is unable to accommodate them. Until this software limitation is overcome this measurement will be handled as a simple distance measurement of 200nm with a standard deviation of 100nm. The position of the *Uco* is considered known to about 10nm.

Some of the German survivors gave distances to the coast in place of or in addition to an absolute position. One of the survivors to give such information was Lieutenant Bunjes who gave the position of sighting as 160nm southwest of North West Cape (Olson, 2000). The other references of this nature are either too vague or obviously in error to be of any use. This type of information would be of great significance to people about to enter lifeboats.

Therefore it is reasonable to assume that the information originated from the Captain or another senior officer. Due to the different nature of the information this measurement type has been considered independent of the latitude and longitude positions given by the survivors. A standard deviation of 30nm for the distance and 15° for the bearing has been chosen to represent the uncertainty in Bunjes' reference to the coast because of memory and the movement of *Kormoran* during the battle.

Eyewitness Reports

Table 3: Eye witness observations

Name	Bearing	Description	Source
A.Cox	305°	Adelina Cox saw a glow out to sea on or beyond the horizon late on the night of 19/20 November 1941.	King, 1998
D.Pluschke	272°	Doug Pluschke, after returning from a school social late in November 1941, witnessed flashes and explosions out to sea. He could just hear the sound of gunfire.	King, 1998
I.Mallard	320°	Ivy Mallard and her husband witnessed smoke and flashes. She is not sure of the date.	McDonald, 1999b
I.Stokes	330°	From her two-storey house on the beach at Horracks Isobella Stokes witnessed flashes to the north-west. The exact date is unknown.	McDonald, 1993
R.Taylor	305°	Beattie Hayes heard gunfire and saw flashes that lit up the sky as she returned from a party at Yallabatharra school.	McDonald, 1993
M.Porter	230°	Marge Porter (then Ridley) heard explosions one night during 1941. She went outside and saw gunfire out to sea.	McDonald, 1993

Part of the evidence available on the *Sydney/Kormoran* engagement comes from people along the coast between Geraldton and Carnarvon who witnessed events they believe to be the battle (Table 3 records a sample of these). Kirsner & Dunn (1998) have been very critical of such oral evidence, arguing that with regards to precise information (such as position and time) that memory will fail and that the "magnitude of the failure will increase with the interval between the original event and the moment of recall". The oral histories concerning the *Sydney* and *Kormoran* battle did not surface until about 40 years after the war and, not surprisingly, are generally vague on exact details, especially time. Kirsner & Dunn (1998) also warn about how the human mind interprets memory so that it is meaningful to them and how memory is influenced by discussion with others. There also exists the possibility that the witnesses saw something completely unrelated to the *Sydney/Kormoran* engagement, such as an electrical storm. Some confusion also exists because of the shelling of Port Gregory by a Japanese submarine at midnight on the 28th of January 1943 and a visit by *Sydney* to Geraldton on the 18-20th of October 1941 (McDonald, 1993, 1997). Assuming that the people concerned witnessed something related to the loss of *Sydney* and *Kormoran* there still remains the difficulty of assigning each measurement to a particular ship. A standard deviation of between twenty and thirty degrees of arc has been chosen to represent the uncertainty in these measurements depending on the source. Most were measured by compass, however some are derived from directions (eg. north-west). The main factor in this is memory.

The maximum distance at which an eyewitness may have been able to see the gunfire and explosions from the battle is unknown. The direct sighting distance can be calculated as $d = 1.15\sqrt{h}$ where *h* is the height of the observer above sea level in feet and *d* is the maximum direct sighting in nautical miles (Great Britain Admiralty, 1958). However, a glow or light reflected from clouds can be seen at much greater distances. Bye and Byron-Scott (1999) gives the visibility threshold of light as 100nm. Such a constraint should be used in conjunction with the eyewitness observations. However, due to the software limitations mentioned previously this has not been done.

DRIFT ANALYSIS AND DIARY RECONSTRUCTION

The purpose of undertaking a drift analysis for this exercise is to predict, or hindcast, the point of origin (splash point) for the objects located by search and rescue vessels following the battle between *Sydney* and *Kormoran.* The hindcasting process undertaken in this project is based upon that used by Bye (2001). Essentially this method simplifies the drift process into two components: ocean current and windage.

Splash point

The exact time of placement for drifting objects in the water is unknown. Following Kirsner & Hughes (1993) the splash point has been set as 1800H/19 Nov. At this time *Kormoran* and perhaps *Sydney* was without power and some of the survivors were in the water and subject to current and wind. However, it is unlikely that all objects entered the water at the same time. For instance some items may have been dislodged during the battle. Therefore, an allowance of half an hour has been included in order to minimise the potential bias and correlation in the drift measurements.

Ocean current

Ocean current is the below surface wave motion of the oceans. A mean value of 6° at 0.16 knots, calculated from the various values given at the 1991 *Sydney* Forum in Fremantle, is used for the sea current. To account for the variation of sea current estimates it was decided that a standard deviation of 20º should be assigned to the direction of the sea current and 0.05 knots for the ocean velocity. Based upon data presented at the *Sydney* Forum it was considered acceptable that the Leeuwin current need not be considered, as it could not have influenced the path of the debris (McCormack and Steedman, 1991; Hughes, 1991).

Windage

Windage is defined Bye (2001) as *Windage = Object Speed / Wind Speed* and contains the effects of local winds blowing against exposed surfaces and the drag encountered by the underwater hull and on the surface of the sea (wind driven current). In theory the direction of leeway is parallel to the local wind, however in practice has a tendency to move off the downwind path and is subject to a great deal of variation (Hughes, 1991). As highlighted in Hughes (1991) experiments have shown that craft with a large keel plane have deviated by up to 45°, and those with a smaller keel have deviated up to 60°. For the purpose of this project a standard deviation of 15° was utilised to model the variation of the leeway vector.

The windage values estimated by Bye (2001) using current and wind profiles calibrated by empirical data for each of the types of object recovered during the search and rescue have been adopted in this project. Windage is the largest component of the drift and any error in the windage will have dramatic an affect on the resultant vectors. Because the windage parameters are not known exactly they have been treated as observations and given a precision of 0.25% of the wind speed. A mean wind speed and direction of 348° at 22 knots with respective precisions of 20° and 5 knots, calculated from the values presented at the 1991 Forum has been used in the drift analysis.

Table 4: Summary of final drift vectors

Drift Object	Bearing	Precision	Distance nm	Precision nm
Carley Float	169°51’	13°30’	303.8	65.1
Float	169°51’	13°30’	299.4	64.2
Green Box	169°51’	13°30’	299.4	63.3
Kohn’s Lifeboat	216°20’	15°39’	209.7	54.3
Lifebelt A	169°51’	13°30’	279.4	59.9
Lifebelt B	169°51’	13°30’	281.4	60.3
Lifebelt C	169°51’	13°30’	299.4	64.2
Meyer’s Lifeboat	216°20’	15°39’	209.7	54.3

Diary Reconstruction

Using a diary kept by German survivor Lieutenant (Baron) Reinhold von Malapert it is possible to reconstruct the journeys of Meyer’s and Kohn’s lifeboats to a point of origin. The drift periods were dealt with as explained previously. The sailing periods were handled by adding the estimated sailing vectors to the ocean current, correcting the direction of sailing to the course made good. Windage is assumed to be included in the estimates of sailing distance made by von Malapert. A precision of 2° was assigned for the bearing of these vectors (taken using a compass) and a precision of 0.10 knots was used for the speed. The time the boats reached the shore is not known precisely so the allowance for error in the drift time has been increased to an hour. A summary of the final drift vectors can be found in Table 4.

NETWORK CONSTRUCTION AND RESULTS

Survey Networks

Survey network theory uses a least squares algorithm to provide a rigorous technique for combining all measurements and their assigned precisions to estimate the position of the unknown points. A great advantage of the least squares algorithm is that it provides an estimate of the precision of the coordinates and the corrections to the measurements (residuals) in the form of standard deviations.

For a single correction (observed minus computed measurement) v, with standard deviation σ_v, the statistic $\frac{v}{\sigma_0 \sigma_v}$ is a Student-T random variable, σ_0^2 is the a posteriori variance factor (Mikhail, 1976). This allows for statistical testing of the measurements, referred to as the local test. After each adjustment is performed, any measurement that may be considered a statistical outlier is removed and the adjustment re-run. Testing is performed at the 95% confidence level. The removal of ‘bad’ measurements continues until all measurements pass the local test or the point of diminishing returns is met. A second statistical test, the global test, is be performed on σ_0 which follows a χ^2 distribution and is representative of the network as a whole (Mikhail, 1976). Refer to Mikhail (1976) for more information on least squares and network testing.

Methodology

Survey networks usually assume that there is no change in the location of object points whilst the measurements are being taken. In this instance the assumption is not true as the measurements are spread over time and the ships were moving. Also some drift objects may have entered the water during the battle while others entered it afterwards and some position are specified at the time of sighting whilst others are given for the battle. To overcome this, the assumption that *Kormoran* sank in the approximate vicinity of the action has been made. All observations that relate to the battle in general shall then be assigned to the *Kormoran*. This assumption is reasonable because, according to most reconstructions of the battle, the movement during the battle spans about 5’ by 10’, which is small in comparison to the range in the measurements. The observations to *Sydney* are assumed to relate to the time at which *Sydney* exploded or sank.

By performing the network adjustment several times the accuracy of the eyewitness observations, the positions given by the Germans and the drift analysis can be tested (i.e. it can be seen how well they fit the other measurements).

Network Design and Results

In the previous sections several doubts or ambiguities in the available measurements have been expressed. Four networks have been designed to assess these ambiguities and test hypotheses.

Network 1

The first network uses what might be considered the most scientifically sound or reliable measurements: the drift vectors, the *Uco* distance and the Geraldton Radio longitude.

Network 1 passes the global test with all measurements satisfying the criteria for the local test. The σ_0 is small (0.7059) indicating that the measurements are more consistent than the precision assigned to them would suggest. This is not surprising as the drift vectors are highly correlated because they have all been calculated using the same parameters.

However, the precisions have not been scaled to make the σ_0 one because they are deemed to be realistic given the lack of meteorological measurements for the region and time of interest. A very large search area (see Table 5) reflects the low weighting of the measurements and the low degrees of freedom. It is no surprise that the search area for *Kormoran* is much smaller than that for *Sydney* given the shortage of information on *Sydney*. Based on the drift vectors alone the position for *Kormoran* is nearly two degrees south of the position given by Detmers.

Network 2

The second network design adds the measurements derived from information provided by the German survivors to the drift, Geraldton Radio and *Uco* measurements used in Network 1. The main purpose of this network is to test the fit of the drift measurements with the German positions.

The distance from North West Cape to *Kormoran* and the distance between *Sydney* and *Kormoran* fail the local tests before the point of diminishing returns is met. The search areas derived from Network 2 are considerably smaller than those from Network 1, mainly because of the increased redundancy in the solution. The position of *Kormoran* is now very close to the positions given by the Germans. This large change in position is evidence of a weak solution, which is not surprising given the absence of any strong datum points. Still it is preferable to retain the objective estimates for the precision developed earlier in the paper.

Network 3

The third network has been designed to test the eyewitness observations. As with Network 2 the drift vectors, Geraldton Radio longitude and *Uco* distance are also used. The assumption has been made that all witnesses observed the battle and therefore all eyewitness measurements have been assigned to *Kormoran*.

The observation by I.Mallard fails the local test. After the removal of this measurement Network 3 passes both the global and local tests. This network design offers no additional measurements to *Sydney* over Network 1 and therefore the position and search area for *Sydney* are the same. The precisions of the calculated coordinates of *Kormoran* have improved over Network 1 due to the increase in redundancy. Based on these results the eyewitness observations agree well with the drift vectors. However, without using estimates or constraints for the sighting distances of the eyewitnesses it is dangerous to make any conclusions based on this.

Network 4

The fourth network design incorporates all of the available measurements. As with Network 3 the eyewitness observations have been assigned to *Kormoran*. This network has the greatest potential to produce an optimised search area because of the relatively large number of observations.

Again, the distance from North West Cape to *Kormoran* and the distance between *Sydney* and *Kormoran* fail the local tests before the point of diminishing returns is met. The results from using all the measurements are relatively close to those from Network 2, which used the drift vectors plus the German positions (see Table 5 for results). This suggests that the positions given by the Germans have higher relative weighting than the other observations in the adjustment. There is no conflict between the eyewitness observations and the positions given by the Germans. This is because of the very low precisions assigned to the eyewitness observations and sighting distances have not been used.

Comments on Results

It is evident from the results that the solution is weak. The large variation in the coordinates and their associated quality estimates between the networks is evidence of a weakness in the datum. Unfortunately there are no sources of evidence that can reasonably be called reliable. Even if the positions given by the Germans are correct they are still only quite rough. The drift analysis is heavily dependent on having accurate knowledge about the ocean current, local winds, drift times and windages. These factors prohibit the determination of a ‘tight’ solution without subjectively favouring individual measurements.

Due to the very small amount of evidence regarding the fate of *Sydney* the last known distance and bearing between *Kormoran* and *Sydney* (a dubious estimate at best) has a significant influence on the solution and the estimates of precision especially.

The final coordinates computed for *Sydney* and *Kormoran* are shown in Table 5. Figure 1 compares the results from Network 4 (which uses all measurements) with positions computed by other researchers. It can be seen that there are substantial variations in the positions and search areas defined by the various researchers. The position for *Kormoran* from this project is close to that estimated by a number of the other researchers. Due to the lack of information, few others have solved for *Sydney’s* position. Knight and Whittaker’s (2001) positions, resulting from an airborne search using their KDLS technology, is markedly different from the positions derived by this project and those of other researchers. The methodology used in constructing the networks assumed that the position for *Kormoran* represented the battle in general. Therefore, it is not surprising that the search areas for *Kormoran* are no smaller than the area covered during the battle. The search area for *Kormoran* compares very favorably to those of other researchers. Only Kirsner & Dunn (1998) give a search area for *Sydney*, which is markedly smaller than that from Network 4.

Table 5: Summary of results from network adjustments

Network	Vessel	Latitude	Longitude	Semi-Major Axis (nm)	Semi-Minor Axis (nm)	Azimuth (degrees)	95% Confidence Region (nm^2)
1	*Sydney*	28° 55’ 40” S	111° 49’ 28” E	39.2	35.6	79.0	26,251
2	*Sydney*	28° 51’ 56” S	112° 03’ 54” E	35.6	31.4	159.3	21,018
3	*Sydney*	28° 55’ 40” S	111° 49’ 28” E	39.2	35.6	79.0	26,251
4	*Sydney*	28° 51’ 59” S	112° 03’ 27” E	35.6	31.2	158.7	20,933
1	*Kormoran*	28° 10’ 02” S	111° 15’ 34” E	26.7	4.8	179.9	2,429
2	*Kormoran*	26° 29’ 01” S	111° 11’ 13” E	7.9	4.1	179.8	616
3	*Kormoran*	27° 49’ 59” S	111° 15’ 39” E	18.0	4.8	179.3	1,633
4	*Kormoran*	26° 30’ 55” S	111° 10’ 20” E	7.6	4.1	179.1	592

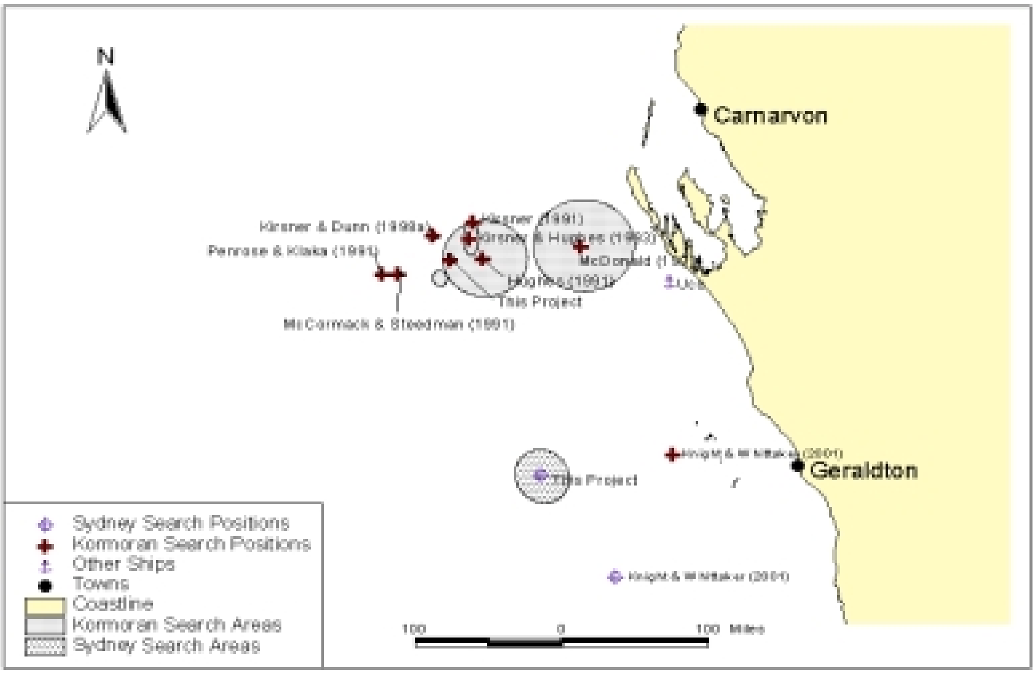

Figure 1: Comparison of solutions by various researchers

CONCLUSION

This project has attempted to determine a best estimate of the search area for HMAS *Sydney* and HSK *Kormoran* by:

- Collecting available evidence suitable for use in a survey network.
- Developing quantitative estimates of the uncertainty contained in each of the items of evidence.
- Performing drift analysis on all suitable debris found during the search and rescue.
- Designing a series of least squares based survey networks to test the weighted measurements and create 95% confidence region search areas.

This project has shown that survey networks have great potential in the definition of search areas for shipwrecks. However, the results produced by the project are by no means final, as not all factors have been taken into consideration (see Further Research). Also, as might be expected the search areas are too large for a deep ocean search to be feasible. However, the research method developed by this project is deemed to be worthy of further development.

REFERENCES

Bye, J.A.T., (2001), *Drift Evidence for the Locations of HMAS Sydney and HKS Kormoran*, Research Report 58, Flinders Institute for Atmospheric and Marine Sciences.

Bye, J.A.T. and Byron-Scott, R.A.D., (1999), *Regional Sound and Light Propagation During the Sinking of HMAS Sydney*, Research Report 57, Flinders Institute for Atmospheric and Marine Sciences.

Detmers, T., (1959), *The Raider Kormoran*, William Kimber, London.

Frame, T., (1998), *HMAS Sydney Loss and Controversy*, Hodder, Rydalmere.

Great Britain Admiralty, (1958), *Manual of Navigation Volume III*, HMSO, London.

Hardstaff, R.J., (1997), Submission No 8 to the *Inquiry into the Circumstances of the Sinking of HMAS Sydney*, The Parliament of the Commonwealth of Australia: Joint Standing Committee on Foreign Affairs, Defence and Trade: Defence Sub-Committee, Canberra.

Hughes, S., (1991), 'A possible solution based on modern search and rescue planning techniques' *in* M. McCarthy and K. Kirsner (compilers), *Papers from the HMAS Sydney Forum, Fremantle 21-23 November, 1991*, Western Australian Maritime Museum.

King, D.R.E., (1998), Submission No 68 to the *Inquiry into the Circumstances of the Sinking of HMAS Sydney*, The Parliament of the Commonwealth of Australia: Joint Standing Committee on Foreign Affairs, Defence and Trade: Defence Sub-Committee, Canberra.

Kirsner, K., (1991), 'Converging operations in historical judgement' *in* M. McCarthy and K. Kirsner (compilers), *Papers from the HMAS Sydney Forum*, Western Australian Maritime Museum.

Kirsner, K. & Dunn, J., (1998), Submission No 135/135A to the *Inquiry into the Circumstances of the Sinking of HMAS Sydney*, The Parliament of the Commonwealth of Australia: Joint Standing Committee on Foreign Affairs, Defence and Trade: Defence Sub-Committee, Canberra.

Kirsner, K., & Hughes, S. (1993*), HMAS Sydney and HSK Kormoran: Possible and Probable Search Areas*, Western Australian Maritime Museum.

Knight, L.C., and Whittaker, T.W., (2001), *The Search for the Wrecks of HMAS Sydney and HSK Kormoran in 1989, 1998, 2001 using the Knight Direct Location System*, Unpublished.

McCormack, M. & Steedman, R.K., (1991) 'Backtracking the lifeboats and floats: a meta ocean view' *in* M. McCarthy & K. Kirsner (compilers), *Papers from the HMAS Sydney Forum, Fremantle 21-23 November, 1991*, Western Australian Maritime Museum.

McDonald, E., (1991), 'Wind, Weather and Wonder' *in* M. McCarthy and K. Kirsner (compilers), *Papers from the HMAS Sydney Forum*, Western Australian Maritime Museum.

McDonald, E., (1999a, 22 August), Personal Communication.

McDonald, E., (1999b, 29 August), Personal Communication.

McDonald, G., (1993), *Seeking the Sydney: A New Perspective in the Search for HMAS Sydney*, Unpublished.

McDonald, G., (1997), Oral History and its Relevance to the Search for HMAS Sydney, *HMAS Sydney Forum*, 1-2 February 1997, Fremantle.

Mikhail, E.M., (1976), *Observations and Least Squares*, IEP, New York.

Montgomery, M. (1981), *Who Sank the Sydney?*, Cassel, Maryborough.

National Archives of Australia: Fleet Radio Unit; B5823, Whole Series, *Detmers' Diary - German Plain-Text and Translated English Versions of the Deck Log and the Engine Room Log of HSK Kormoran.*

National Archives of Australia: MP1587/1 164K, *Sinking of the Cruiser "Sydney" - 19-11-1941. (Extract from the diary of Lt-Comdr. Bretschneider, Officer of the "Kormoran".*

Olson, W., (2000), *Bitter Victory: The Death of HMAS Sydney*, University of Western Australia Press, Nedlands.

Penrose, J.D. and Klaka, K.P., (1991), 'Notes on the movement of the wreck material from the area of the Sydney / Kormoran engagement' *in* M. McCarthy & K. Kirsner

(compilers), *Papers from the HMAS Sydney Forum, Fremantle 21-23 November, 1991*, Western Australian Maritime Museum.
Winter, B., (1984), *HMAS Sydney Fact, Fantasy and Fraud*, Boolarong Publications, Brisbane.

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