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KAINJI LAKE RESEARCH INSTITUTE
TECHNICAL REPORT SERIES NO.13

A COMPUTER PROGRAMME FOR CALCULATING THE AREA COLONIZED BY EMERGENT MACROPHYTES IN LAKE KAINJI

By

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Erratum

Page 6 paragraph 2 the second sentence should read:

"If the plants depend for successful establishment on mud wetted by rainfall, conditions in a drought situation may have been too harsh for proper establishment of the plant population"

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Abstract

A FORTRAN programme which calculates the maximum area of Lake Kainji colonizable by macrophyte vegetation in a given year, and the productivity of *Echinochloa stagnina* is given and explained.

A modified version of the programme which calculates the amount of nitrogen and phosphorus removable from the Lake if *Echinochloa stagnina* is managed, by harvesting, as a renewable source of dry season livestock fodder is also presented.

The uses and limitations of the programmes are discussed.

INTRODUCTION

The emergent vegetation of Lake Kainji has attracted widely varied interests. Whilst the power generation authority view the vegetation as a problem to the lake's hydrology and a threat to the life expectancy of the lake (Fregene pers. comm.), fishery experts see the vegetation as a valuable spawning and breeding ground for a number of economically important fish species (Imevbore and Bakare, 1974; Ita *et al*, 1982). Cattle farmers, both resident and the semi-nomadic Fulani view *Echinochloa stagnina* (Retz.) P. Beav., the major component (92.6% frequency) of the vegetation as a valuable source of dry season fodder for their stock. Wildlife experts see the vegetation as the only hope left for the return of the Manatee, a herbivorous mammal that lived in the River Niger before the impoundment.

With such varied interest in the vegetation, there is need to manage and maintain it within "safe" limits such that while it does not affect power generation significantly, it satisfies the need of the wildlife/tourism, cattle and fishery industries.

Such management can only be based on a knowledge of the cover dynamics of the vegetation in order to plan control measures well ahead. Cover data could be obtain from LANDSAT imageries but these are difficult to buy and are grossly out-dated when they finally arrive. This report presents computer programme which calculates the maximum area colonizable by the vegetation in a given year using the maximum and minimum water levels of the previous year. The programme also calculates the productivity of *Echinochloa*.

stagnina, the nitrogen and phosphorus removable from the lake if 75% of the standing crop of Echinochloa stagnina is harvested.

The Kainji reservoir, 9°50' - 10°55'N; 4°25' - 4°45'E closed on 2nd August, 1968 is 136.8km maximum length and 24.1km maximum width. Its surface area has been variously quoted as 1270km^2 (Willoughby, 1974); 1250km^2 (Imevbore and Bakare, 1974); in this work the surface area is approximated to 1300km^2. At full volume, the water level is at altitude 142m, maximum depth 60m, mean depth 11m.

The Lake is bordered by Sokoto and Niger States on the eastern shore and Kwara State on the western shore.

RESERVOIR ENVIRONMENT

Climate

The climate is seasonal, tropical with a distinct rainy season (April - October) and a dry season (November - March). The peak of the rainfall occurs between July and September. The ambient temperature are generally high. The lowest day temperatures are recorded in December and January, while the highest are recorded in April before the out set of the rains. Wind speed is generally low during the dry season (4km/hr) and higher (10km/hr) during the rainy season. Live squalls with wind speed to 90km/hr do occur during the early rains. Lake surface temperature is between 29 and 31°C but falls to 26°C between February and April (Henderson, 1973).

Geology

The geology of the Lake site has been summarized by Halsteed, 1975.

The wester margin of the Lake basin is bordered by upper Crestaceous classics of the Nupe formation. The southern and northern margins are bordered by a variety of rock types belonging to the basement complex. The floor of the Lake consists mainly of silty alluvium.

Lake Hydrology

The Lake is sustained by two annual floods. One originates from areas around the source of the River Niger in Guinea. The water from this catchment passes through semi-desert areas and deltaic swamps around Timbuctu where it loses much of its silt and about 65% of its water by evaporation and infiltration before it reaches Kainji Lake in November, nearly six months later. This is called the "Black flood". The other, the "White flood" originates from the drainage area of River Niger south of Niamey. The drainage from this catchment area and the river Sokoto with its tributaries is heavily laden with giving a milky white appearance. The retention time of the Lake is about 76 days, implying that the Lake flushes itself four times in the year. The Lake rises and falls about 10m annually. The lowest level is reached in August, but the Lake is essentially full from November to March.

Presence of Vegetation and its Probable Effects

The presence of the emergent vegetation of the Lake was first reported by Imevbore (1971) who estimated that less than 0.5% of the Lake surface area was covered by vascular plant communities.

Hall (1975) described the macrophyte communities of Lake Kainji as made up of *Echinochloa* sp., *Cyperus* sp., *Pistia stratiotes* and *Cratophyllum demorsum*. In 1977, using a combination of a side looking radar imagery (February 1977) and a ground-truth survey, Chachu (1977) estimated that 84.6km² or 8.9% of the Lake was covered by plants mainly *Echinochloa* sp. Chachu (1977) used for the surface area of the Lake, the 950km² which he surveyed for ground-truth.

PROGRAMME DEVELOPMENT

DEFINITIONS

A 'draw-down period' in this study refers to the period between the highest water elevation and the lowest water elevation of a given year. A 'flood period' refers to the period between the lowest water elevation of a given year and the highest water elevation of the next year (effectively; August - January).

A 'new area' is the exposed mud which has remained inundated during the previous draw-down period.
An 'acquired area' is an area of draw-down which maintains a stand of vegetation for two consecutive draw-down periods.

CONCEPT

The concept (Kainji Lake Echinochloa Model, Morton and Obot, 1984) is based on the colonization characteristic of Echinochloa stagnina which is the major component of the vegetation.

For each 1m drop in water elevation, up to 80km² of mud is exposed (Henderson, 1973). This mud can be colonized by Echinochloa stagnina and other emergent macrophytes provided the mud is wet enough for seed germination and establishment. The mud is exposed during the rainy season so conditions are usually suitable for establishment.

If the exposed area is 'new', it is colonized mainly by seedlings. A colonized new area may become 'acquired' if it is exposed in the next draw-down period. If the area is not exposed, the colonizing plants of the previous draw-down usually die. An acquired area may also, remain inundated during the next draw-down period. Plants in such areas are also killed.

An acquired area may stay exposed for more than two flood cycles. In this situation, the mud may become dry enough for other terrestrial plants to establish and the area will be lost to the emergent plants due to competition. Thus, the depth classes and consequently, the area of draw-down colonized and acquired by the emergent macrophytes for a given year (in January) is largely determined by the highest water elevation (January) and the lowest water elevation (August) of the previous year.

Echinochloa stagnina and other emergent macrophytes have not been observed growing in the Lake rooted in areas deeper than 9.5m. This depth is reffered to as DMAX; the maximum depth in which the emergent plants can survive.

In any particular, UL is the upper water limit (January) and LL is the lower water limit (August) of the previous year (Figure 1). D is an array which denotes the classes (0.1m) which can potentially be colonized in a particular year i.e. form UL to LL (when LL is less than DMAX) or UL to DMAX (when LL $\geqslant$ DMAX). 'A' is an array which contains the additional area of mud exposable in each depth class (Table 1), subdivided equally within each 1m depth class.

The area of mud which is potentially colonized in any particular year (AREA) is therefore, given by:-

$$AREA = \sum_{i=1}^{m} A_i \quad D_i$$

where m is the total number of depth classes which could be exposed in any year.

The percentage area of the Lake occupied by the macrophytes (PCT) is given by:-

$$PCT = \frac{AREA \times 100}{1300}$$

PROGRAMME VERIFICATION

Using this concept, a FORTRAN programme was written to simulate the expected depth classes in which the macrophytes are expected to root for the year 1972 to 1973.

The area colonizable in any given year is shown in Figure 2.

The programme accurately simulates the area colonized by the grass in 1977 as observed on SLAR imagery of February 1977 (Figure 3) but there appear to be large differences between the observed and calculated values in years prior to 1977 (Figure 2).

The programme calculates the potential area colonizable (the environmental potential) in any one year but the calculation of the actual area colonized by the plant should take into account the early years of the lake when the vegetation must have been building up its population towards the environmental potential, controlled probably by its intrinsic reproductive rate (the biological potential). The plant are obviously capable of attaining the environmental potential rapidly e.g. from 16% to 33% between 1976 and 1977 (LANDSAT March 1976 Figure 4 and SLAR February 1977 Figure 3), a reproductive rate of 2.1. An explanation is needed for its apparent inability to attain the environmental potential during the period 1974-1976, assuming a similar reproductive rate applied to the 1972 LANDSAT data.

One explanation is based on the fact that the last Sahelian drought affected Kainji in 1972/73 (Ita et al, 1982). If the plants depend, for successful establishment of the plant population. There seems to be no reason, however, why the environmental potential should not have been achieved between 1974-1976 after the drought. In fact, no LANDSAT data are available at present for 1973-1975, so it is not known whether this potential was actually achieved. An explanation for the discrepancy in 1976 is still needed, however. The satellite images were taken in February and March respectively; while the programme 'predicts' the population of the grass in January. It is known that the grass is harvested by cattle farmers for their stock and professional harvesters who sell the grass to the nomadic Fulani herdsmen. Thus, the imageries record what is left of the potential maximum standing crop less harvest.

MODIFICATION OF THE PROGRAMME TO INCORPORATE HARVESTING AND SUBSEQUENT REGROWTH

Two factors were introduced into the programme.

1) The actual area colonized (ACT) controlled by a reproduction factor (R)

2) The visible area colonized (VIS), i.e. actual area colonized less harves.

The reproductive rate of the population was based on the reproductive rate of the major component of the population of Echinochloa stagnina.

A mean reproductive rate of 5.1 was estimated from tiller density and seed production data. Eight seed collectors were randomly placed in the grass stand and viable seeds trapped in the collectors were counted daily through the fruiting season (November to February). Mean viable seed collected was 1009 seeds/m². Mean tiller density was 197 tiller/m² (tiller density in January, 1982).

From field observations it is known that when the plants are cut above water, the nodes maintained above water become active, producing new tillers. However, when the plant is cut below water it dies and the stem starts to decay within a few days. Cutting occurs both above and below water but cutting below water is more frequent as this is far easier than cutting above water level. In the programme, the 'worst' situation - cutting below water - is assumed. That is all plants harvested are killed.

The proportion of the total colonized area harvested was introduced into the programme as the variable CUT.

The raltionship betwen ACUT, VIS and CUT are as follows:-

$$ACT = VIS \times R \text{ (or } ACT = PCT \text{ if } vis \times R < PCT)$$

$$VIS = ACT \times \frac{(100 - CUT)}{100}$$

It is most probable that the practice of cutting the grass for livestock had not in 1972, reached the highly commercial stage it has reached at present, probably because the local people did not realize its commercial value so were too busy with re-settlement problems. In that case, the LANDSAT value for March 1972 would be equal to ACT. Starting with the 1972 value of ACT, (10.8%) the programme was applied for zero cutting regime (CUT = 0) and reproductive rates of 2 and 5.1 (Figure 4). With r = 5.1, the environmental potential could have been achieved in one year with a low value of R (R = 2), the environmental potential could very nearly have been achieved in two years.

The results of varying the cutting regime are shown in Figure 5 and it can be seen that a cutting regime of between 50 and 60% could account for the figure produced from LANDSAT imagery in 1976. In the model, the same cutting regime is simulated over all years, but in reality it would vary from year to year e.g. the 1977 SLAR imagery suggests virtually no cutting occurred in 1977

HOW TO USE THE PROGRAMME

Input Data

To calculate the area of lake potentially covered in the "next" year the following information for the current year must be defined:-

1. Upper water level UL (usually available in January)

2. Lower water level LL (usually available in August)

3. Reproductive rate R (the present reproductive rate for Echinochloa stagnina is 5.1).

The progrmme can also be used for making management decisions; for example, if Echinochloa stagnina is to be maintained as a renewable source for livestock fodder, a given percentage chould be left unharvested.

If the plant has a reproductive rate greater than 4 for instance about 75% of the standing crop can be harvested.

For management decision making, the variable CUT (the percentage standing crop to be harvested) must be defined. For the present, CUT = 75% is recommended. When CUT is defined, the programme calculates.

1. Area of the lake potentially colonized (AREA)

2. Percentage potential area colonized (PCT)

3. Actual area colonizable (ACT)

4. Potential productivity (PROD)

5. Actual productivity (APROD)

6. Visible area colonized (VIS)

7. Utilizable standing crop (UT)

8. Nitrogen removable from the system (NREM)

9. Phosphorus removable from the system (PREM)

The potential productivity (standing crop) is given by:-

$$PROD = \sum_{i=1}^{m} P_i \; D_i \; A_i$$

APRO (actual productivity) is a function of ACT and PCT; and is given by $APROD = PROD \times \frac{ACT}{PCT}$

UT (utilizable standing crop) = 0.1 x APROD
NREM (nitrogen removable from the lake system when 75% of the standing crop is harvest) is given by NREM = 0.02 UT
PREM (phosphorus removable from the lake ecosystem when 75% of the standing crop is harvested is given by PREM = 0.002 UT.

The programme and a typical result sheet are shown in Figures 6 and 7 respectively.

It is more practical to make management decisions on area basis based probably on available labour for harvesting. Area to be harvested can thus, be defined as HARV. HARV can be set to a high value. The relationship between CUT and HARV is given by:-

$$CUT = \frac{HARV \times 100}{AAREA}$$

$$AAREA = \frac{1300 \times PCT}{100}$$

A modified version of the programme automatically converts HARV to 75% of area covered if HARV is greater than AREA and calculates the area harvestable (AREAH). Calculation of the area harvestable takes into consideration of the fact that if more than 75% of the population is cut, (Reproductive rate of 5.1) the population will extinct.

The modified programme and its result sheet are shown in Figures 8 and 9 respectively.

These programmes are easily adapted to systems using FORTRAN IV. For systems that use BASIC the programmes can be translated easily to BASIC.

USES AND LIMITATIONS OF THE PROGRAMME

The programme calculates the area covered by the vegetation assuming an equilibrium state. In a disturbed situation (for example during a high level of polution), there may be differences between the calculated area and the observed area. This may be useful as a means of monitoring ecosystem disturbance in the lake.

CONCLUDING STATEMENTS

Using the programmes presented, it is possible to predic the extent of the vegetation cover of the Lake for a given year well in advance for management plans that may require such data. LANDSAT imageries will obviously give the most accurate data but at present the imageries are difficult to buy and are grossly outdated when they finally arrive.

The use of the KAINJI LAKE ECHINOCHLOA MODEL to estimate the vegetation cover data will also save the cost of aerial surveys which is the immediate alternative to LANDSAT Imageries.

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Table 1 - Hypsographic chart for Kainji Lake (Modified from Table 2 of Henderson (1973)

Height of Upper surface (m above M/S/L)	Lake Volume ($m^3 \times 10^9$)	Area of 1-m Statum ($m^3 \times 10^9$)	Incremental Area of Mud Exposed (km^2)
142	15.6	1.30	0
141	14.4	1.24	60
140	13.2	1.17	70
139	12.0	1.11	60
138	10.9	1.05	60
137	9.9	.99	60
136	8.85	.92	70
135	7.95	.86	60
134	7.10	.78	80
133	6.30	.73	50
132	5.60	.67	60
131	4.90	.63	
130	4.3	.58	
129	3.7	.53	
128	3.25	.48	
127	2.75	.43	
126	2.3	.39	
125	1.9	.35	
124	1.55	.31	
123	1.25	.26	
122	1.0	.22	not
121	.85	.18	usually
120	.7	.14	exposed
119	.6	.09	
118	.5	.07	
117	.4	.05	
117	.35	.04	
115	.30	.03	
114	.25	.02	
113	.2	.01	
112	.1	.005	
111	.05	-	
110	-	-	

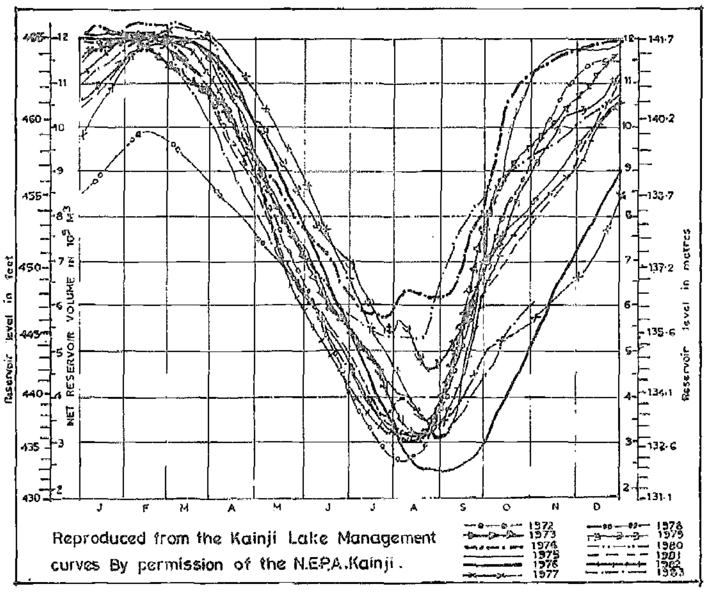


Fig. 1 Kainji Lake Management Curve.

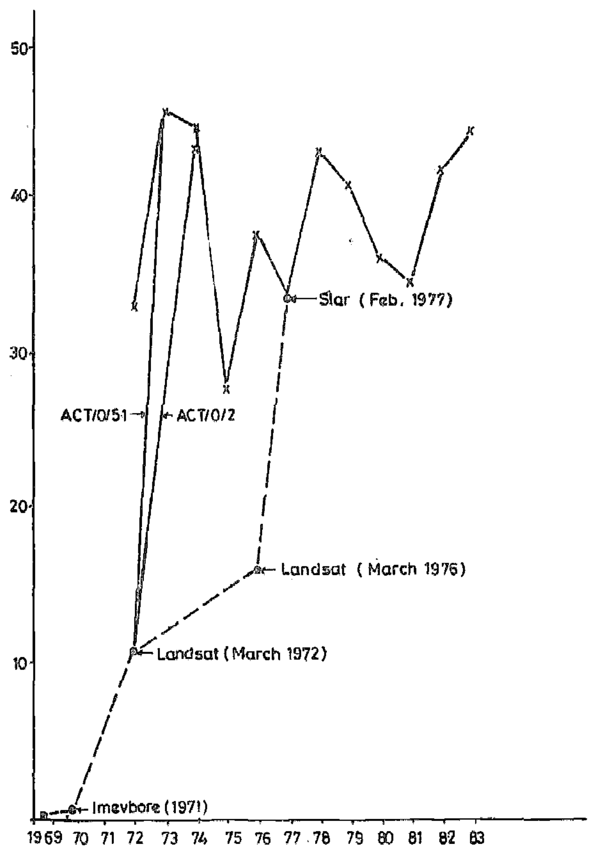


Fig 2 Percentage area of Lake Kainji covered by Emergent Vegetation: Comparision between Calculated and Observed cover.

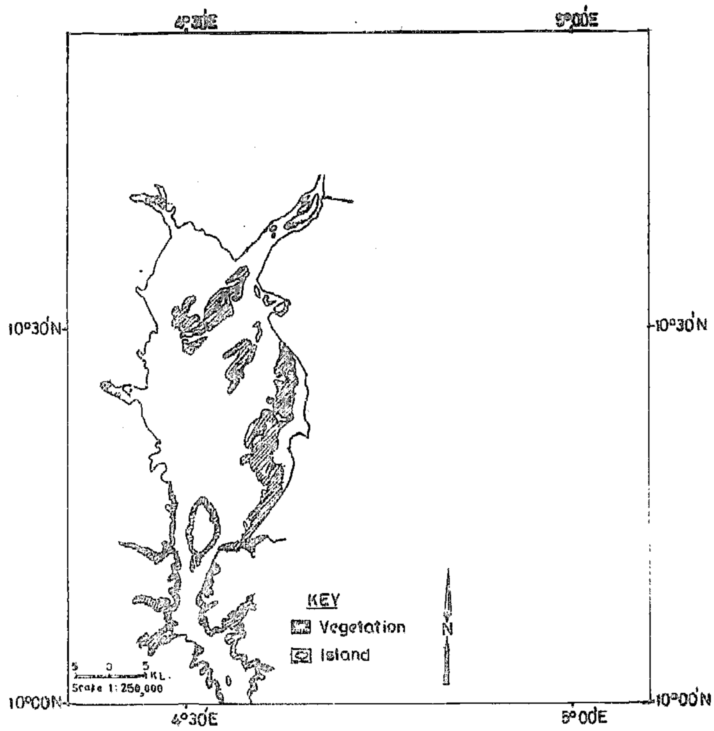


Fig. 3. Side looking air borne radar mosaic
1st Feb 1977

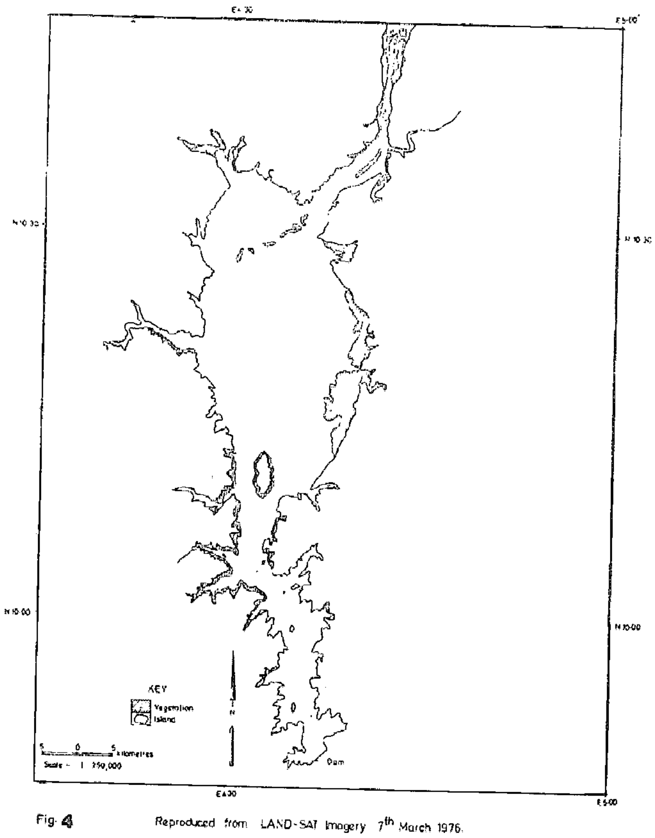


Fig. 4 Reproduced from LAND-SAT Imagery 7th March 1976.

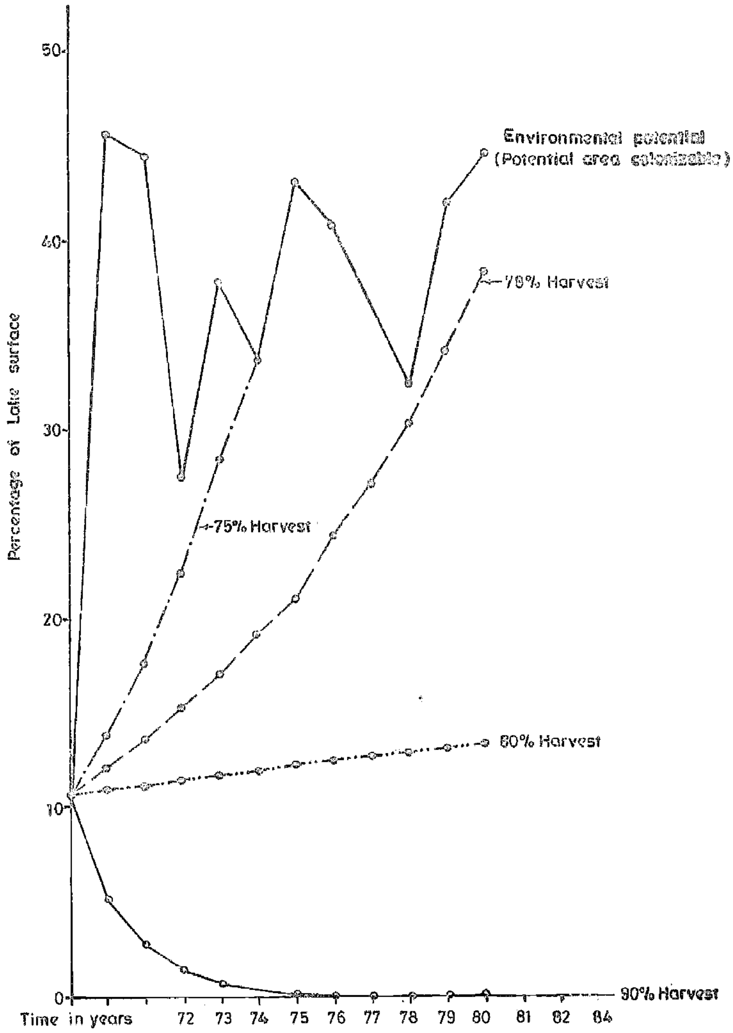
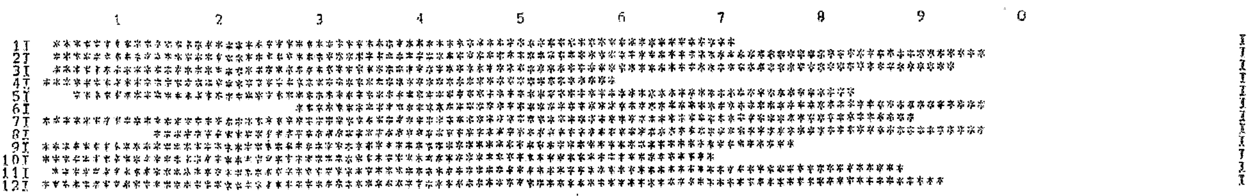


Fig. 8. Calculated area colonizable by E. stagnina at cutting regimes 75%–90% assuming a 5·1 reproductive rate

FIG. 6 PROGRAMME; KAINJI LAKE **ECHINOCHLOA** MODEL

```
000000B          REAL NREM
000000B          REAL LL
000000B          INTEGER T(120)
           C     THE ARRAYS ARE DIMENSIONED,XMIN(N),XMAX(N),X(M),A(M*10.,Y(M),
           C     P(M*10)
           C     WHERE N = NUMBER OF YEARS
           C           M= NUMBER OF DEPTH CLASSES
           C     X = AREA EXPOSEABLE IN EACH 1M DEPTH CLASS
000000B          DIMENSION XMIN(20),XMAX(20),X(12),A(120),ST(120,20),Y(12),P(120)
002131B          DATA IBL,IAST/1H ,1H*/
           C     Y= STANDING CROP FOR EACH 1M DEPTH CLASS
           C     DMAX = MAX DEPTH AT WHICH ECHINOCHLOA CAN SURVIVE
           C     R=REPRODUCTIVE RATE
           C     CUT= PROPORTION OF ECHINOCHLOA HARVESTED BELOW WATER LEVEL
002131B          DMAX=9.5
007545B          R=5.1
           C     READ NUMBER OF YEARS
007547B          CUT=75
007550B          READ (5,1)N
           C     READ MIN AND MAX WATER LEVEL FOR EACH YEAR
007561B          READ(5,2)(XMIN(I),XMAX(I),I=1,N)
007613B          READ(5,8)(X(I),I=1,12)
           C     READ STANDING CROP FOR EACH 1M DEPTH CLASS
007633B          READ(5,22)(Y(I),I=1,12)
007653B          K=0
007653B          DO 9 I=1,12
007656B          DO 9 J=1,10
007661B          K=K+1
007662B          A(K)=X(I)/10.
007673B          P(K)=Y(I)
007704B        9 CONTINUE
007712B          WRITE (6,7)
007720B          WRITE (6,14)
           C     EQUATE UPPER COLONIZABLE LIMIT(UL)AND LOWER COLONIZABLE LIMIT(LL)
           C     TO XMAX AND XMIN
007726B          DO 3 I=1,N
007735B          UL=XMAX(I)
007741B          LL=XMIN(I)
           C     SET LOWER COLONIZABLE LIMIT EQUAL TO DMAX
007746B          IF (LL.GT.DMAX)LL=DMAX
           C     CALCULATE AND PRINT DEPTH CLASS COLONIZABLE FOR EACH YEAR.
007752B          DO 4 J=1,120
007754B          ST(J,I)=0.
007762B        4 T(J)=IBL
007772B          K=UL*10.
007774B          L=LL*10.
007776B          DO 5 J=K,L
010010B          ST(J,I)=1.
010016B        5 T(J)=IAST
010027B          WRITE(6,6)I,T
010041B        3 CONTINUE
010045B          WRITE (6,13)
           C     CALCULATE AREA POTENTIALLY COLONIZED
           C     CALCULATE PRODUCTIVITY
010053B          DO 10 I=1,N
010062B          AREA=0.
010062B          PROD = 0
010063B          DO 11 J=1,110
010067B          AREA=AREA+A(J)*ST(J,I)
010102B          PROD = PROD+A(J)*P(J)*ST(J,I)
010110B       11 CONTINUE
           C     CALCULATE PERCENTAGE OF LAKE SURFASE POTENTIALLY COLONIZED
010113B          PCT =AREA/1300.*100.
010115B          IF(I.GT.1)GO TO 15
010117B          ACT= 10.8
010120B          GO TO 16
           C     CALCULATE ACTUAL PERCENTAGE AREA COVERED BEFORE HARVEST BASED ON
           C     LAST YEAR LEFT-OVER
010122B       15 ACT=VIS*R
(49) - CAUTION  -----------------------------------------------------------VIS IS NOT SET ABOVE
010121B          IF(ACT.GT.PCT)ACT=PCT
           C     CALCULATE AND PRINT LEFT-OVER(USUALLY VISIBLE ON LANDSAT)
010130B       16 VIS=ACT*(100.-CUT)/100.
010134B          APROD=PROD*ACT/PCT
           C     CALCULATE UTILIZABLE BIOMASS IN TONNES
010136B          UT=0.1*APROD
010137B          NREM=.02*UT
010140B          PREM=0.002*UT
010142B          WRITE (6,12)I,AREA,PCT,PROD,ACT,APROD,VIS,UT,NREM,PREM
010163B       10 CONTINUE
010167B          WRITE(6,29)
010175B          WRITE (6,17)
010203B          WRITE(6,18)
010211B          WRITE(6,19)
010217B          WRITE(6,23)
010225B          WRITE(6,30)
010233B          WRITE(6,26)
010241B          WRITE(6,27)
010247B          WRITE(6,28)
010255B          WRITE (6,24)
010263B          WRITE(6,25)Y
010273B          WRITE (6,20)CUT
010302B          WRITE (6,21)R
010311B        1 FORMAT (I2)
010311B        2 FORMAT (16F5.0)
010311B        6 FORMAT(1X,I2,1HI,120A1,1HI)
010311B        7 FORMAT(1H1,1X,29HKAINJI LAKE ECHINOCHLOA MODEL//)
010311B        8 FORMAT (16F5.0)
010311B       12 FORMAT(//1X,I2,9F10.1)
010311B       13 FORMAT(/,7X,4HAREA,8X,3HPCT,6X,4HPROD,8X,3HACT,5X,5HAPROD,
                1 6X,3HVIS,4X,5HUT(T),4X,7HNREM(T),4X,7HPREM(T))
010311B       14 FORMAT(12X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,9X,1H7,9X,1H8,
                1 9X,1H9,9X,1H0/)
010311B       17 FORMAT(1X,39HPCT = POTENTIAL PERCENTAGE AREA COVERED)
010311B       18 FORMAT(1X,36HACT = ACTUAL PERCENTAGE AREA COVERED)
010311B       19 FORMAT(1X,47HVIS = VISIBLE (LANDSAT) PERCENTAGE AREA COVERED)
010311B       20 FORMAT(/1X,6HCUT = ,F5.0)
010311B       21 FORMAT(/1X,4HR = ,F5.1)
010311B       22 FORMAT (16F5.0)
010311B       23 FORMAT(1X,44HPROD = POTENTIAL TOTAL STANDING CROP(TONNES))
010311B       24 FORMAT(//1X,39HSTANDING CROP FOR EACH 1M DEPTH(TONNES))
010311B       25 FORMAT(1X,16F7.0)
010311B       26 FORMAT(1X,37HUT = UTILIZABLE STANDING CROP(TONNES))
010311B       27 FORMAT (1X,31HNREM = NITROGEN REMOVED(TONNES))
010311B       28 FORMAT(1X,33HPREM = PHOSPHORUS REMOVED(TONNES))
010311B       29 FORMAT(//1X,28HPOTENTIAL ARCA COVERED(KME2))
010311B       30 FORMAT(1X,36HAPROD = ACTUAL STANDING CROP(TONNES))
010311B          STOP
010312B          END
```

FIG. 7 KAINJI LAKE *ECHINOCHLOA* MODEL: RESULT SHEET



	AREA	PCT	PROD	ACT	APROD	VIS	UT(T)	NREM(T)	PREM(T)
1	428.0	32.9	1194774.0	10.8	391930.5	2.7	39193.1	783.9	78.4
2	593.0	45.6	1606374.0	13.8	484919.1	3.4	48491.9	969.8	97.0
3	579.0	44.5	1606374.0	17.6	631316.9	4.4	63431.7	1268.6	126.9
4	360.0	27.7	800488.0	22.4	647068.1	5.6	64706.8	1294.1	129.4
5	492.0	37.8	1524066.0	28.5	1149334.7	7.1	114933.5	2298.7	229.9
6	439.0	33.8	1382140.0	33.8	1382140.0	8.4	138214.0	2764.3	276.4
7	558.0	42.9	1595544.0	42.9	1595544.0	10.7	159554.4	3191.1	319.1
8	531.0	40.8	1531640.0	40.8	1531640.0	10.2	153164.0	3063.3	306.3
9	470.0	36.2	1396248.0	36.2	1396248.0	9.0	139624.8	2792.5	279.2
10	422.0	32.5	1136280.0	32.5	1136280.0	8.1	113628.0	2272.5	227.3
11	544.0	41.8	1580392.0	41.4	1563096.6	10.3	156309.7	3126.2	312.6
12	579.0	44.5	1612872.0	44.5	1612872.0	11.1	161287.2	3225.7	322.6

POTENTIAL AREA COVERED(KM2)
PCT = POTENTIAL PERCENTAGE AREA COVERED
ACT = ACTUAL PERCENTAGE AREA COVERED
VIS = VISIBLE (LANDSAT) PERCENTAGE AREA COVERED
PROD = POTENTIAL TOTAL STANDING CROP(TONNES)
APROD = ACTUAL STANDING CROP(TONNES)
UT = UTILIZABLE STANDING CROP(TONNES)
NREM = NITROGEN REMOVED(TONNES)
PREM = PHOSPHORUS REMOVED(TONNES)

STANDING CROP FOR EACH 1M DEPTH(TONNES)
1083. 1625. 1625. 1625. 2166. 5416. 5416. 5416. 1083. 0 0 0

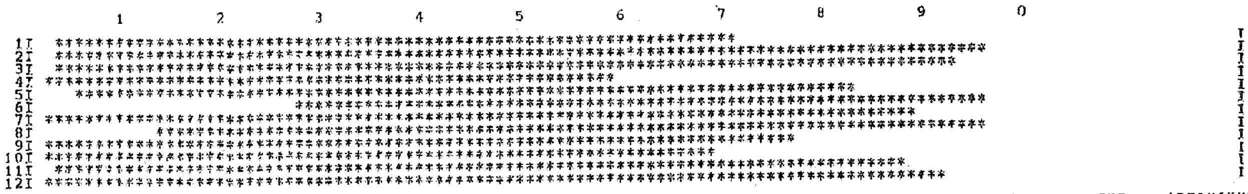
CUT = 75.

R = 5.1

FIG. 8 PROGRAMME; KAINJI LAKE **ECHINOCHLOA** MODEL: HARV (HARVEST) INCORPORATED

```
  1.   0000000B           REAL NREM
  2.   0000000B           REAL LL
  3.   0000000B           INTEGER T(120)
                    C     THE ARRAYS ARE DIMENSIONED,XMIN(N),XMAX(N),X(M),A(M*10.,Y(M),
                    C     P(M*10)
                    C     WHERE M = NUMBER OF YEARS
                    C           N= NUMBER OF DEPTH CLASSES
                    C     X = AREA EXPOSEABLE IN EACH 1M DEPTH CLASS
  4.   0000000B           DIMENSION XMIN(20),XMAX(20),X(12),A(120),ST(120,20),Y(12),P(120)
  5.   0021313B           DATA IBL,IAST/1H ,1H*/
                    C     Y= STANDING CROP FOR EACH 1M DEPTH CLASS
                    C     DMAX = MAX DEPTH AT WHICH ECHINOCHLOA CAN SURVIVE
                    C     R=REPRODUCTIVE RATE
                    C     CUT= PROPORTION OF ECHINOCHLOA HARVESTED BELOW WATER LEVEL
  6.   0021313B           DMAX=9.5
  7.   0075458B           R=5.1
                    C     READ NUMBER OF YEARS
  8.   0075478B           CUTMAX=75
  9.   0075508B           HARV=420
 10.   0075528B           READ (5,1)N
                    C     READ MIN AND MAX WATER LEVEL FOR EACH YEAR
 11.   0075628B           READ(5,2)(XMIN(I),XMAX(I),I=1,N)
 12.   0076148B           READ(5,8)(X(I),I=1,12)
                    C     READ STANDING CROP FOR EACH 1M DEPTH CLASS
 13.   0076348B           READ(5,22)(Y(I),I=1,12)
 14.   0076548B           K=0
 15.   0076548B           DO 9 I=1,12
 16.   0076578B           DO 9 J=1,10
 17.   0076628B           K=K+1
 18.   0076638B           A(K)=X(I)/10.
 19.   0076748B           P(K)=Y(I)
 20.   0077058B         9 CONTINUE
 21.   0077138B           WRITE (6,7)
 22.   0077218B           WRITE (6,14)
                    C     EQUATE UPPER COLONIZABLE LIMIT(UL)AND LOWER COLONIZABLE LIMIT(LL)
                    C     TO XMAX AND XMIN
 23.   0077278B           DO 3 I=1,N
 24.   0077368B           UL=XMAX(I)
 25.   0077428B           LL=XMIN(I)
                    C     SET LOWER COLONIZABLE LIMIT EQUAL TO DMAX
 26.   0077478B           IF (LL.GT.DMAX)LL=DMAX
                    C     CALCULATE AND PRINT DEPTH CLASS COLONIZABLE FOR EACH YEAR
 27.   0077538B           DO 4 J=1,120
 28.   0077558B           ST(J,I)=0.
 29.   0077638B         4 T(J)=IBL
 30.   0077738B           K=UL*10.
 31.   0077758B           L=LL*10.
 32.   0077778B           DO 5 J=K,L
 33.   0100118B           ST(J,I)=1.
 34.   0100178B         5 T(J)=IAST
 35.   0100308B           WRITE(6,6)I,T
 36.   0100428B         3 CONTINUE
 37.   0100468B           WRITE (6,13)
                    C     CALCULATE AREA POTENTIALLY COLONIZED
                    C     CALCULATE PRODUCTIVITY
 38.   0100548B           DO 10 I=1,N
 39.   0100638B           AREA=0.
 40.   0100638B           PROD = 0
 41.   0100648B           DO 11 J=1,110
 42.   0100798B           AREA=AREA+A(J)*ST(J,I)
 43.   0101038B           PROD = PROD+A(J)*P(J)*ST(J,I)
 44.   0101118B        11 CONTINUE
                    C     CALCULATE PERCENTAGE OF LAKE SURFACE POTENTIALLY COLONIZED/
 45.   0101148B           PCT =AREA/1300.*100.
 46.   0101168B           IF(I.GT.1)GO TO 15
 47.   0101208B           ACT= 12.8
 48.   0101218B           GO TO 16
                    C     CALCULATE ACTUAL PERCENTAGE AREA COVERED BEFORE HARVEST BASED ON
                    C     LAST YEAR LEFT-OVER
 49.   0101238B        15 ACT=VIS*R
(49) - CAUTION  ----------------------------------------------------VIS IS NOT SET ABOVE
 50.   0101258B        16 IF(ACT.GT.PCT)ACT=PCT
 51.   0101338B           AAREA=1300*ACT/100.
 52.   0101348B           IF(HARV.GT.0)CUT=HARV/AAREA*100.
 53.   0101428B           IF(CUT.GE.CUTMAX)CUT=75
                    C     CALCULATE AND PRINT LEFT-OVER(USUALLY VISIBLE ON LANDSAT)
 54.   0101468B           VIS=ACT*(100.-CUT)/100.
 55.   0101508B           APROD=PROD*ACT/PCT
 56.   0101528B           AREAH=AAREA*CUT/100.
                    C     CALCULATE UTILIZABLE BIOMASS IN TONNES
 57.   0101548B           UT=0.1*APROD
 58.   0101558B           NREM=.02*UT
 59.   0101578B           PREM=0.002*UT
 60.   0101608B           WRITE(6,12)I,AREA,PCT,PROD,ACT,AAREA,APROD,VIS,UT,NREM,PREM,CUT,
                         1AREAH
 61.   0102058B        10 CONTINUE
 62.   0102118B           WRITE(6,29)
 63.   0102178B           WRITE (6,17)
 64.   0102258B           WRITE(6,23)
 65.   0102338B           WRITE(6,18)
 66.   0102418B           WRITE(6,31)
 67.   0102478B           WRITE(6,30)
 68.   0102558B           WRITE(6,19)
 69.   0102638B           WRITE(6,26)
 70.   0102718B           WRITE(6,27)
 71.   0102778B           WRITE(6,28)
 72.   0103058B           WRITE(6,32)
 73.   0103138B           WRITE (6,24)
 74.   0103218B           WRITE(6,25)Y
 75.   0103318B           WRITE(6,20)HARV
 76.   0103408B           WRITE (6,21)R
 77.   0103478B         1 FORMAT (I2)
 78.   0103478B         2 FORMAT (16F5.0)
 79.   0103478B         6 FORMAT(1X,I2,1HI,120A1,1HI)
 80.   0103478B         7 FORMAT(1H1,1X,29HKAINJI LAKE ECHINOCHLOA MODEL//)
 81.   0103478B         8 FORMAT (16F5.0)
 82.   0103478B        12 FORMAT(//1X,I2,12F10.1)
 83.   0103478B        13 FORMAT(/,7X,4HAREA,9X,3HPCT,4X,4HPROD,9X,3HACT,5X,5HAAREA,
                         14X,5HAPROD,9X,3HVIS,4X,5HUT(T),4X,7HNREM(T),4X,7HPREM(T),6X,3HCUT,
                         24X,11HAREAH(KM2))
 84.   0103478B        14 FORMAT(12X,1H1,9X,1H2,9X,1H3,9X,1H4,9X,1H5,9X,1H6,9X,1H7,9X,1H8,
                         19X,1H9,9X,1H0/)
 85.   0103478B        17 FORMAT(1X,39HPCT = POTENTIAL PERCENTAGE AREA COVERED)
 86.   0103478B        18 FORMAT(1X,36HACT = ACTUAL PERCENTAGE AREA COVERED)
 87.   0103478B        19 FORMAT(1X,47HVIS = VISIBLE (LANDSAT) PERCENTAGE AREA COVERED)
 88.   0103478B        20 FORMAT(/1X,7HHARV = ,F5.0)
 89.   0103478B        21 FORMAT(/1X,4HR = ,F5.1)
 90.   0103478B        22 FORMAT (16F5.0)
 91.   0103478B        23 FORMAT(1X,44HPROD = POTENTIAL TOTAL STANDING CROP(TONNES))
 92.   0103478B        24 FORMAT(//1X,39HSTANDING CROP FOR EACH 1M DEPTH(TONNES))
 93.   0103478B        25 FORMAT(1X,16F7.0)
 94.   0103478B        26 FORMAT(1X,37HUT = UTILIZABLE STANDING CROP(TONNES))
 95.   0103478B        27 FORMAT (1X,31HNREM = NITROGEN REMOVED(TONNES))
 96.   0103478B        28 FORMAT(1X,33HPREM = PHOSPHORUS REMOVED(TONNES))
 97.   0103478B        29 FORMAT(//1X,35HAREA = POTENTIAL AREA COVERED(KM2))
 98.   0103478B        30 FORMAT(1X,36HAPROD = ACTUAL STANDING CROP(TONNES))
 99.   0103478B        31 FORMAT(1X,33HAAREA = ACTUAL AREA COVERED(KM2))
100.   0103478B        32 FORMAT(1X,30HAREAH = AREA HARVESTABLE(KM2))
101.   0103478B           STOP
102.   0103508B           END
```

FIG. 9 KAINJI LAKE ECHINOCHLOA MODEL: RESULT SHEET; HARV. (HARVEST) INCORPORATED



	AREA	PCT	PROD	ACT	AAREA	APROD	VIS	UT(T)	NREM(T)	PREM(T)	CUT	AREAH(KME2)
1	428.0	32.9	1194774.0	10.8	140.4	391930.5	2.7	39193.1	783.9	78.4	75.0	105.3
2	593.0	45.6	1606374.0	13.8	179.0	484919.1	3.4	48491.9	969.8	97.0	75.0	134.3
3	579.0	44.5	1605374.0	17.6	228.2	634316.9	4.4	63431.7	1268.6	126.9	75.0	171.2
4	360.0	27.7	809188.0	22.4	291.0	647068.1	5.6	64706.8	1294.1	129.4	75.0	218.3
5	492.0	37.8	1524056.0	28.5	371.0	1149334.7	7.1	114933.5	2298.7	229.9	75.0	278.3
6	439.0	33.8	1382140.0	33.8	439.0	1382140.0	8.4	138214.0	2764.3	276.4	75.0	329.3
7	558.0	42.9	1595544.0	42.9	558.0	1595544.0	10.7	159554.4	3191.1	319.1	75.0	418.5
8	531.0	40.8	1531640.0	40.8	531.0	1531640.0	10.2	153164.0	3063.3	306.3	75.0	398.2
9	470.0	36.2	1396248.0	36.2	470.0	1396248.0	9.0	139624.8	2792.5	279.2	75.0	352.5
10	422.0	32.5	1136280.0	32.5	422.0	1136280.0	8.1	113628.0	2272.6	227.3	75.0	316.5
11	544.0	41.8	1583392.0	41.4	538.0	1563096.6	10.3	156309.7	3126.2	312.6	75.0	403.5
12	579.0	44.5	1612872.0	44.5	579.0	1612872.0	12.2	161287.2	3225.7	322.6	72.5	420.0

AREA = POTENTIAL AREA COVERED(KME2)
PCT = POTENTIAL PERCENTAGE AREA COVERED
PROD = POTENTIAL TOTAL STANDING CROP(TONNES)
ACT = ACTUAL PERCENTAGE AREA COVERED
AAREA = ACTUAL AREA COVERED(KME2)
APROD = ACTUAL STANDING CROP(TONNES)
VIS = VISIBLE (LANDSAT) PERCENTAGE AREA COVERED
UT = UTILIZABLE STANDING CROP(TONNES)
NREM = NITROGEN REMOVED(TONNES)
PREM = PHOSPHORUS REMOVED(TONNES)
AREAH = AREA HARVESTABLE(KME2)

STANDING CROP FOR EACH 1M DEPTH(TONNES)
1083. 1625. 1625. 1625. 2166. 5416. 5416. 5416. 1083. 0 0 0

HARV = 420.

R = 5.1

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