# IMPORTING PARASITOIDS FOR MANAGEMENT OF CODLING MOTH AND SECONDARY PESTS IN PEARS

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## ABSTRACT

As an exotic pest, the codling moth has very few natural enemies in California and it is the key pest of walnut, apple and pear production in the state. In its region of origin in Central Asia codling moth is attacked by a number of parasitoid species that help to prevent it from being of importance as a pest. The aim of this project has been to import the most important parasitoid species from Central Asia, and to release and establish them in Californian orchards. Three parasitoid species were collected from orchards in Kazakstan and Xinjiang; two ichneumonid cocoon parasitoids, *Liotryphon caudatus* and *Mastrus ridibundus*, and one braconid larval parasitoid, *Microdus rufipes*. The two ichneumonid parasitoids were readily cultured in our insectary to provide large numbers of individuals for field release in California. We were unable to culture the braconid parasitoid in the insectary, and relied on direct release of field collected parasitoids. Through this project we field released about 46,000 individuals of the solitary cocoon parasitoid, *L. caudatus*, at 41 locations in California. It has become established in the region, but after initial rates of parasitism as high as 30% in release orchards typical rates of parasitism are less than 5%. Approximately 317,000 individuals of the gregarious cocoon parasitoid, *M. ridibundus*, have been field released at 65 locations in California. This species has also become established and parasitism rates range from less than 10% to greater than 50%. Only 200 individuals of the solitary larval parasitoid, *Microdus rufipes*, have been field released at 5 locations in California and we have not made any recoveries of this species. The project has been very successful in establishing two of the three key Central Asian parasitoids in California. The impact of these parasitoids on overwintering populations of the codling moth appears to be sufficiently high for them to be of significance in reducing the pressure from codling moth on pear production in the future.

## JUSTIFICATION

The codling moth, *Cydia pomonella* (L.), is the key pest in pear orchards and requires successive intervention through the season to suppress damage levels at harvest. The continued development of multiple resistance to insecticides in codling moth populations, throughout the western region, has encouraged growers to consider alternative sustainable pear pest management practices. It is unlikely that there will be a single solution for codling moth management in the future and therefore it is important for researchers to combine their expertise in the development of an integrated control package for codling moth in pears. Pheromone-mediated mating disruption currently offers the most promising immediate alternative to insecticide treatments for codling moth suppression. The conversion from Guthion or Pencap-M to pheromone control permits natural enemies and biological control, that have previously been excluded by reliance on insecticides, to be integrated into codling moth management.

As an exotic pest in the U.S., the codling moth is unconstrained by natural enemy control and pressure from this pest remains particularly high in California where it achieves a greater number of generations each season. In Central Asia, the original home of the codling moth, we have seen no evidence of attack in pears due to the low level of codling moth pressure in this region. The importation and establishment of specialized parasitoids from Central Asia to restore a natural balance in codling moth populations in California has led to the probable establishment of two parasitoid species. However, further releases are needed to increase the range of establishment within the state, and additional parasitoid species would add further to the potential for control.

The reduced reliance on broad-spectrum insecticides associated with adoption of mating disruption as a primary tactic for codling moth management has led to concern over secondary pests such as leafrollers, pear psylla and true bugs. As both leafrollers and pear psylla occur in Central Asia, the potential to use additional parasitoid species from this ancestral region for management of secondary pests in pear orchards in California also needs to be explored.

## OBJECTIVES

The overall aim of this project is to restore the natural balance in codling moth and secondary pest populations in pear orchards in California through the importation, release and establishment of specialized parasitoids from Central Asia. The specific objectives for the 2000 season were:

1. To continue the collection of parasitoids of codling moth from Kazakstan and the Xinjiang Province of China, and extend surveys to secondary pests, particularly leafrollers and pear psylla.
2. To field release *Mastrus ridibundus* and *Microdus rufipes*, and monitor their establishment and impact on codling moth in pear orchards in California.

## PROCEDURES

### Objective 1. To continue the collection of parasitoids of codling moth from Kazakstan and the Xinjiang Province of China, and extend surveys to secondary pests, particularly leafrollers and pear psylla.

#### *Codling moth*

The origin of the codling moth is Central Asia, perhaps Kazakstan, where apple forests commonly grow in the foothills of the Tien Shan mountains and where specialized parasitoids help to maintain codling moth populations at a low level of abundance (Fig. 1). However, wild apples also occur in the valleys running south into Xinjiang Province, the northwest corner of China. In previous years we have been able to make collections of codling moth by banding trees in abandoned variety trial orchards in southern Kazakstan, in the region around Almaty. The objective over the last two years has been to extend the foreign exploration for parasitoids of the codling moth to Xinjiang in the hope of being able to field collect greater numbers of the braconid larval parasitoid, *Microdus rufipes*. We have been unsuccessful in rearing this species in captivity in our insectary and have had to rely on collecting sufficient material for direct release into Californian orchards. While *M. rufipes* was collected in some numbers in southern Kazakstan in 1995-96, we have been unable to collect sufficient material more recently. The opportunity to collect in Xinjiang arose through collaboration with Dr. Li Baoping of the Agricultural University in Urumqi.

Dr. Li was able to band trees in the Illi Valley of Xinjiang with strips of corrugated cardboard to trap parasitized codling moth larvae as they descend the tree to seek cocooning sites under the bark of the trunk. Collections of parasitized codling moth larvae were made in each of the two generations of codling moth (early July and September) in 1999 and during the first generation of codling moth (early July) during the 2000 season. The Illi Valley contains an expanding number of commercial apple orchards and almost all now use pesticide treatments for control of a range of arthropod pests including spider mites, scales and codling moth. As a result there are very few parasitoids present in these commercial orchards. Nonetheless, there are also some wild trees that grow in the region and these trees were banded for collection of parasitized codling moth larvae.

Following recovery of the bands from the field, cocoons of codling moth were cut out of the bands and sent via DHL from Urumqi to our quarantine in Berkeley. The transit time was approximately 5 days and the cocoons arrived in good condition each time. The material from the summer collections was directly set up in sleeve cages in our quarantine facility to await emergence of unparasitized moths and parasitoid adults. The cocoons from the September collection were first set up in a sleeve cage for 2-3 weeks in quarantine to allow for the emergence of any parasitoids that were not in diapause. They were then placed in cold storage in a refrigerator at 5°C for 6 months of overwintering before being taken out and placed into a sleeve cage again to await emergence. The emerging parasitoids were first identified and subsequently were placed into rearing cages in the insectary to increase numbers for field release.

***Secondary Pests***

I also made a trip to Almaty in Kazakstan in May 2000 to make collections of parasitoids from leafrollers and pear psylla on pears in this region. There had been strong spring frosts with greater rainfall than usual, and as a consequence insect populations were particularly low in abundance. The fruit tree region from Kaskellan, just west of Almaty, to Chilik, east of Almaty, were searched for codling moth, leafrollers and pear psylla. As there was no evidence of codling moth in the variety trial orchards this year we decided not to band trees for the collection of codling moth parasitoids. There was also no evidence of pear pylla, but leafroller populations could be found sporadically in low numbers throughout the region.

**Objective 2. To field release *Mastrus ridibundus* and *Microdus rufipes*, and monitor their establishment and impact on codling moth in pear orchards in California.**

*Releases*

During the 1999-2000 field seasons we field released *Mastrus ridibundus* only. From 1,000 to 4,000 individuals of *M. ridibundus* were released during the 2000 field season at each of 10 field sites, located in 8 counties. Releases were made in 5 walnut orchards, 3 pear orchards and 2 apple orchards to maximize the probability for establishment of the parasitoid in the region. The releases began on August 29 and continued through to November 6. Releases were confined to orchards in which insecticides were not being applied.

*Recoveries*

We monitor the establishment and impact of the parasitoids by banding trees in the orchards to recover codling moth larvae descending from the fruit to pupate. The bands were placed out in July and August to collect the diapausing codling moth larvae and were recovered from the orchards in November. The bulk of the recovered codling moth and parasitoids are allowed to complete diapause by storage at 2°C for four months and then are allowed to emerge at 20°C in the insectary. The emerging parasitoids that have developed from successful attacks of codling moth in California are then added to our insectary culture. However, the codling moth cocoons recovered from a smaller sub-sample of bands from the orchards are dissected to determine the level of parasitism at the release sites.

Theory suggests that a biological control agent is more effective if it shows a positive aggregative response to the density of its host. To determine the response of *M. ridibundus* to codling moth cocoon density under field conditions we studied the patterns of parasitism in the tree bands. For each band, the number of codling moth cocoons was determined as well as the number of parasitized cocoons in order to calculate the probability of parasitism for each banded tree. An increase in the probability of parasitism in relation to cocoon density would provide evidence of an aggregative response.

## RESULTS

*Foreign Exploration for Codling Moth Parasitoids in Xinjiang*

The parasitoid species recovered from the collections in the Illi Valley were very similar to those recovered previously from the neighboring region of southern Kazakstan (Table 1). The most notable difference, however, was the absence of the egg-prepupal braconid parasitoid *Ascogaster quadridentata* from Xinjiang. This absence is rather surprising as *A. quadridentata* is the most ubiquitous parasitoid of codling moth worldwide. It is the most consistent parasitoid of codling moth throughout Europe and is also known throughout North America, Australasia and South Africa.

*Quarantine Rearing*

For the first time this year since we first obtained *M. rufipes* in 1995, we were able to produce female offspring in captivity. The female parasitoids have always been observed to mate successfully in captivity, but they have never shown much interest in attacking codling moth infested thinning apples in sleeve cages either in the quarantine facility or the insectary. However, this year was the first time that we were able to use the newly renovated quarantine facility on the Oxford Tract of the Berkeley campus. This facility has a glasshouse addition that was used for rearing out the parasitoids from both the September 1999 collection, following cold storage over winter, and the June 2000 collection.

The mated female *M. rufipes* showed much more interest in codling moth attacked apples than we had seen before and both male and female offspring were produced for the first time. On removing the culture from the quarantine glasshouse to the insectary, parasitoids showed less interest in attacked apples. However, on returning the culture to the quarantine glasshouse again the female offspring again renewed their interest in attacked apples. We also noted that successful parasitism was associated only with mid stage codling moth larvae and only with younger rather than mature apples. The success of parasitism by *M. rufipes* in captivity in the new quarantine glasshouse suggests that strong natural daylight has been the important environmental cue that has been missing in all previous attempts to rear this species in captivity.

*Field Releases of Codling Moth Parasitoids*

A total of 40,000 individuals of *M. ridibundus* were field released between August 29 and November 6 in a series of 5 walnut orchards, 3 pear orchards and 2 apple orchards (Table 2). This very successful set of releases brings the total number of *M. ridibundus* released in California to 316,986 individuals at 65 different sites (Table 3).

By comparison, a total of 45,981 individuals of *L. caudatus* were field released between 1991 and 1997 and a total of 196 individuals of *M. rufipes* were field released between 1995 and 1997 (Table 3). As *M. ridibundus* is a gregarious parasitoid producing on average 3-4 individuals per host attacked, greater number can be produced more effectively from insectary rearing. However, during the years 1997 to 2000 we concentrated heavily on the production of this species as it appeared to be the most effective parasitoid under field conditions in California. Our rearing program for *M. ridibundus* proved to be particularly effective and we were able to release enormous numbers of this species in many different orchards throughout the state. The switch to rearing codling moth larvae on thinning apples rather than artificial diet was the single most important factor facilitating the production of greater numbers of parasitoids for field release.

*Field Recoveries of Codling Moth Parasitoids*

Recoveries of both *L. caudatus* and *M. ridibundus* have been made from a number of orchards in which parasitoids have been released in previous years, indicating that these two species have both become established in California. So far we have not made any recoveries from the relative small releases of *M. rufipes*, and it seems unlikely that this species has become established.

The orchards that were monitored for parasitism during the 2000 field season have yet to be analyzed. However, a summary of the recoveries from the years 1993-99 is presented in Table 4 for monitoring carried out in apples, pears and walnuts. *L. caudatus* was field released during the years 1993-97 and *M. ridibundus* from 1995-2000. The orchards monitored from 1993-96 were all orchards in which parasitoids had been released during the year of monitoring. Only the walnut orchards monitored in 1997 received same season parasitoid releases, and none of the orchards monitored in 1998-99 received same season parasitoid releases during this period. Thus parasitism observed in the apple and pear orchards in 1997 and in all orchards in 1998-99 resulted from parasitoids successfully established in previous years.

Parasitism by *L. caudatus* was as high as 25% in orchards during a year of parasitoid release, as was the case in a walnut orchard monitored in Gridley in 1993. However, after releases ceased in 1997, this parasitoid species has been found only sporadically and apparently more in apples than the other two commodities. In the case of *M. ridibundus,* first released in 1995, parasitism has been as high as 57% of the overwintering population in an apple orchard monitored in Brentwood in 1997, a year in which no parasitoids were released in that orchard. Parasitism by *M. ridibundus* has also been much more consistent than that of *L. caudatus* in an orchard once parasitoid releases ceased.

Lab observations indicate that *M. ridibundus* is frequently unable to attack codling moth cocoons through the corrugated cardboard and must enter the flutes of the bands to access their host. When collected from the orchards in November the bands are full of overwintering spiders and it appears that the more abundant the spiders the lower the level of parasitism. Thus it appears that spiders may be an important impediment to the successful monitoring of parasitism by *M. ridibundus* in tree bands. Recent observations by Tom Unruh (USDA-Yakima Lab, WA) suggest that parasitism of codling moth by *M. ridibundus* in natural settings under the bark of apple trees is up to four times greater than determined from tree bands.

*Field Efficiency of Mastrus ridibundus*

The rates of parasitism found in the tree bands shows that within an orchard, females parasitize more cocoons on trees that have a high level codling moth damage compared to trees with low damage. (Fig. 2a). When different orchards are compared *M. ridibundus* performs better in orchards that have higher levels of codling moth damage (Fig. 2b) than in orchards that have low damage. These two responses suggest that *M. ridibundus* shows the aggregative response expected of an effective biological control agent.

*Foreign Exploration for Parasitoids of Secondary Pests in Kazakstan*

Two leafroller species *Archips rosana* and *Pandemis chondrillana* occur in the region, primarily on pear but also on apple. Despite the lateness of the season this year, *A. rosana* had already reached pupation by the third week of May, whereas *P. chondrillana* were present as final instar larvae. After considerable effort making collections of leafroller larvae over a period of one week, 100 leafrollers or parasitoid cocoons had been collected and were returned to our quarantine facility in Berkeley. There were two key parasitoids present in the leafroller collections, a *Diadegma* species (Ichneumonidae) and a *Pseudoperichaeta* species (Tachinidae). The *Diadegma* sp. was of greatest interest as large numbers of hyperparasitized cocoons of this parasitoid had been seen in late June in previous years. From the 100 leaf rolls we obtained 30 cocoons of *Diadegma* sp., most of which had been collected as cocoons in the field. A broad range of hyperparasitoid species were reared from 23 of the 30 cocoons, leaving just 7 *Diadegma* adults, 4 males and 3 females that emerged.

The females mated successfully in quarantine and were tested for their ability to attack larvae of the obliquebanded leafroller (OBLR) and apple pandemis (PAND). In the absence of knowledge of the preferred larval instars for attack the female parasitoids were offered from $1^{st}$ to $3^{rd}$ instars. The parasitoids showed no interest in leafroller larvae outside of their leaf rolls, and appeared to be unable to attack the larger $3^{rd}$ instar larvae. They showed greatest interest in $1^{st}$ instar larvae and so 10 $1^{st}$ instars of either OBLR or PAND were presented to each female each day over a period of about 2 weeks. The larvae of PAND appeared to be of slightly greater interest then those of OBLR, but both hosts were stung and appeared to be attacked successfully. However, in all cases parasitoid attack either led to the premature death of the host larvae by the end of the $2^{nd}$ instar, or if host larvae survived, they did not provide successful completion of development by the parasitoid. Whether attack of $2^{nd}$ or $3^{rd}$ instar host larvae would have proved to be more compatible is not known, but these initial observations suggest that the *Diadegma* sp. is not physiologically compatible with our leafroller species.

## CONCLUSIONS

Extensive field releases of *L. caudatus* from 1991-96 and of *M. ridibundus* from 1995-00, have led to between-season recoveries of both parasitoids from codling moth bands in several different climatic zones. These recoveries are very encouraging, as they provide substantial evidence that the parasitoids are established in the region, and that the project has been a success. It appears that *M. ridibundus* will be the most important parasitoid of the codling moth in California and that it is likely to have a significant impact on overwintering codling moth populations in orchards that are free from insecticide treatments. With increasing emphasis on mating disruption and IGR's for the management of codling moth in the future, it seems likely that parasitism from these imported parasitoids will become a characteristic of commercial orchards as well as reducing codling moth populations in non-managed sites throughout the state.

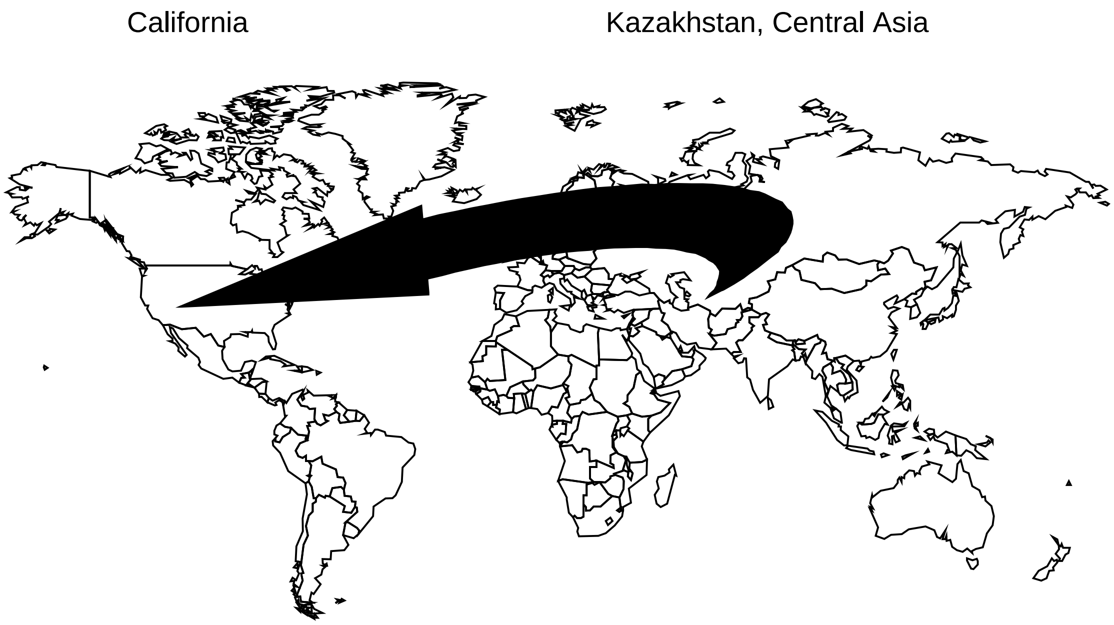


Fig. 1. Region of origin of the codling moth and the source of parasitoids for importation to California

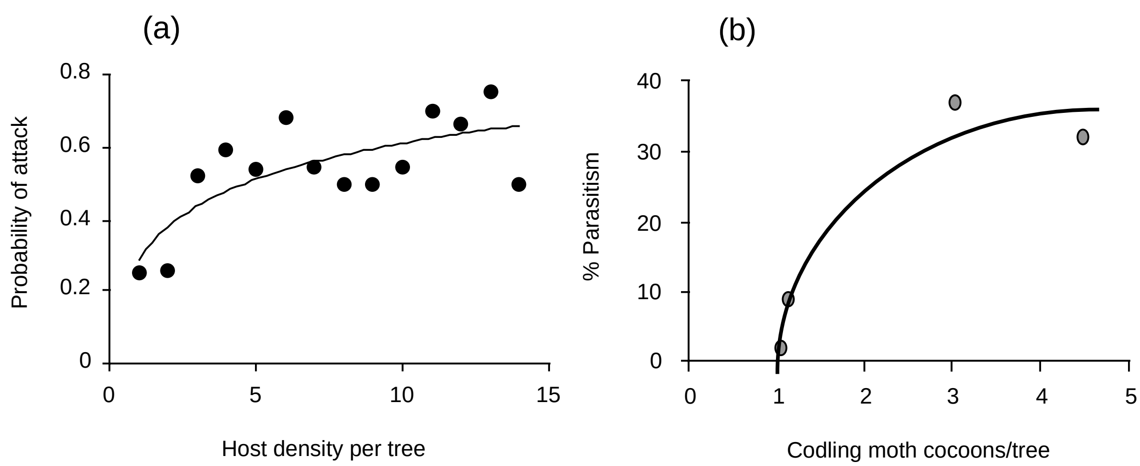


**Fig 2.** Efficiency of *Mastrus ridibundus* under field conditions. Shown are (a) the probability of at least one codling moth cocoon being parasitized in relation to the number of codling moth cocoons trapped in a tree band, and (b) for a number of orchards, the average percentage parasitism in relation to the average number of codling moth cocoons that were found in a tree band in each orchard.

**Table 1.** A comparison of parasitoid species recovered from Kazakstan and Xinjiang.

| Parasitoid species | Family | Guild | Kazakstan | Xinjiang |
|---|---|---|---|---|
| *Ascogaster quadridentata* | Braconidae | Egg-prepupal endoparasitoid | Yes | No |
| *Microdus rufipes* | Braconidae | Larval endoparasitoid | Yes | Yes |
| *Pristomerus vulnerator* | Ichneumonidae | Larval endoparasitoid | Yes | Yes |
| *Liotryphon caudatus* | Ichneumonidae | Solitary cocoon ectoparasitoid | Yes | Yes |
| *Mastrus ridibundus* | Ichneumonidae | Gregarious cocoon ectoparasitoid | Yes | Yes |
| *Dibrachys cavus* | Pteromalidae | Pupal endoparasitoid | Yes | Yes |
| *Apechthis* sp. | Ichneumonidae | Pupal endoparasitoid | No | Yes |

**Table 2.** Releases of *Mastrus ridibundus* during the 2000 field season

| County | Orchard | Commodity | Number released |
|---|---|---|---|
| Contra Costa | 1 | Walnut | 6000 |
| Contra Costa | 2 | Apple | 1700 |
| Kern | 3 | Apple | 6000 |
| Merced | 4 | Walnut | 2600 |
| Mendecino | 5 | Pear | 8000 |
| San Benito | 6 | Walnut | 3250 |
| Santa Cruz | 7 | Pear | 5350 |
| Sacramento | 8 | Pear | 2600 |
| Tehama | 9 | Walnut | 3500 |
| Tulare | 10 | Walnut | 1000 |

**Table 3.** A summary of the releases of parasitoids that have taken place from 1992-2000.

| Parasitoid species | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Liotryphon caudatus*** | | | | | | | | | | |
| Cumulative | 163 | 1627 | 8680 | 15132 | 25599 | 36981 | 45981 | | | |
| Current year | 163 | 1464 | 7053 | 6452 | 10467 | 11382 | 9000 | | | |
| ***Mastrus ridibundus*** | | | | | | | | | | |
| Cumulative | | | | | 10850 | 40036 | 79186 | 161986 | 276986 | 316986 |
| Current year | | | | | 10850 | 29186 | 39150 | 82800 | 115000 | 40000 |
| ***Microdus rufipes*** | | | | | | | | | | |
| Cumulative | | | | | 38 | 165 | 196 | 196 | 196 | 196 |
| Current year | | | | | 38 | 127 | 31 | 0 | 0 | 0 |

**Table 4.** A summary of the recoveries of *Liotryphon caudatus* and *Mastrus ridibundus* from orchards monitored between 1993-99. The data are presented separately for each orchard monitored in each year with orchards categorized by commodity. The total number of overwintering codling moth larvae trapped in bands in each orchard (the sample size for estimation of parasitism) is also provided.

| Year | CM | Walnut | | CM | Apple | | CM | Pear | |
|---|---|---|---|---|---|---|---|---|---|
| | No. | *Liotryphon* | *Mastrus* | No. | *Liotryphon* | *Mastrus* | No. | *Liotryphon* | *Mastrus* |
| 1993 | 350 | 24.57% | | | | | | | |
| 1994 | 121 | 4.13% | | 196 | 3.57% | | 324 | 0.30% | |
| | 110 | 0.00% | | 302 | 2.32% | | 1006 | 1.09% | |
| 1995 | 169 | 0.00% | | 90 | 0.00% | | 160 | | 5.00% |
| | 111 | 0.00% | 10.81% | 575 | 0.00% | | 23 | 8.69% | 21.74% |
| | 28 | 7.14% | 28.57% | | | | | | |
| 1996 | | | | 800 | 0.38% | 5.13% | | | |
| | | | | 315 | 0.32% | 1.59% | | | |
| | | | | 823 | 1.33% | 0.12% | | | |
| 1997 | 154 | 0.00% | 6.49% | 556 | 1.08% | 38.13% | 2 | 50.00% | 0.00% |
| | 50 | 4.00% | 14.00% | 272 | 0.74% | 56.99% | | | |
| | 19 | 0.00% | 10.53% | | | | | | |
| 1998 | 226 | 0.00% | 0.00% | 1000 | 0.00% | 19.20% | 140 | 0.00% | 0.71% |
| | 136 | 0.00% | 0.00% | 444 | 0.00% | 0.00% | 78 | 0.00% | 0.00% |
| | 159 | 0.00% | 0.00% | 325 | 0.00% | 0.62% | 16 | 0.00% | 0.00% |
| | 2355 | 0.00% | 0.17% | 271 | 0.00% | 1.11% | | | |
| | 60 | 0.00% | 0.00% | | | | | | |
| 1999 | 636 | 0.00% | 5.69% | 247 | 0.00% | 28.03% | 38 | 0.00% | 2.63% |
| | 380 | 0.00% | 8.31% | 398 | 0.00% | 25.41% | 64 | 0.00% | 0.00% |
| | 162 | 0.00% | 10.04% | 400 | 2.87% | 36.75% | 102 | 0.00% | 4.90% |
| | 22 | 0.00% | 12.50% | 13 | 14.29% | 0.00% | | | |
| | 305 | 0.00% | 10.94% | | | | | | |
| | 152 | 0.00% | 36.86% | | | | | | |
| | 16 | 0.00% | 0.00% | | | | | | |
| | 26 | 0.00% | 0.00% | | | | | | |
| | 26 | 0.00% | 0.00% | | | | | | |
| | 49 | 0.00% | 4.12% | | | | | | |
| | 224 | 0.00% | 31.02% | | | | | | |